DECOMPOSITION, FUNCTION, AND MAINTENANCE OF ORGANIC MATTER IN A SANDY NURSERY SOIL

By

KENNETH RICHARD MUNSON

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Kenneth Richard Munson

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Decomposition of organic soil amendments (OM) and their effects on soil properties and seedling growth were examined in a Florida forest nursery. Peat was applied at 22.4, 44.8, and 67.2 mt/ha to field macroplots, with and without fumigation. Peat, sewage sludge, shredded pine cones, and old pine sawdust applied at 22.4, 44.8, and 89.6 mt/ha were tested in field microplots. Two slash pine (*Pinus elliottii* var. *elliottii* Engelm.) crops were grown in the macro- and microplots. In a third study, CO_2 evolution was monitored during laboratory incubation of the foregoing materials, plus pine bark and pulp mill waste, in nursery soil.

About 20% of the peat applied at the higher rates in the macroplots had decomposed after 21 months. Soil reaction was lowered below the control by 0.3 pH unit/1% peat.

Seedlings from peat-treated plots were heavier, and had greater N and P concentrations than control seedlings. Seedlings from fumigated subplots had greater dry matter, but lower concentrations of most nutrients, than those from unfumigated soil.

After 18 months the loss rates of OM in the microplots at, respectively, the 22.4, 44.8, and 89.6 mt/ha additions were as follows: Peat, 62, 51, 51%; sludge, 51, 54, 44%; cones, 51, 68, 68%; sawdust, 73, 53, 50%. Peat decomposed 2 - 2½ times more rapidly in the microplots than in the macroplots.

As in the macroplots, peat lowered soil reaction. Cones and sawdust lowered pH slightly after 12 months. Sludge increased pH from 5.7 to 6.5 initially, then reduced it to 4.8 after 3 months.

Peat decomposed without appreciable changes in N/OM ratios. The high N concentration (5.6%) in sludge resulted in leaching of NO_3^- and bases.

Seedlings from peat-amended soil had greater shoot-N contents, and those from sludge-treated plots had greater concentrations of most elements than control seedlings. Cones or sawdust did not reduce growth or N-uptake below the control.

Under laboratory conditions for 7 months, < 5% of the sawdust, cones, and bark had decomposed. Sludge, mill waste, and peat lost 10, 11, and 1%, respectively, of the added carbon.

GENERAL INTRODUCTION

Increasing demands for wood products and a decreasing area of productive forest land emphasize the need for efficient reforestation procedures. In the United States over 2 million acres were artificially reforested in 1980, principally by planting seedlings grown in specialized forest nurseries. Most of this planting stock, 1.4 billion, was grown as "bare root" seedlings. Thus, reforestation programs begin in the nursery with production of quality stock that will meet the objective of survival and growth after outplanting.

Nursery management practices such as cultivation, fumigation and entire seedling removal place intense demands on the soil resource. Without preventative measures the resource can be rapidly depleted, resulting in a loss of productivity (Thompson and Smith 1947). This loss may be manifested by seedlings of low quality with a low potential to survive once outplanted.

One such preventative measure is organic matter (OM) maintenance. Such maintenance, however, is the most common problem associated with nursery soil management (Abbott and Fitch 1977). Nurseries are normally established on sites characterized by well-drained, sandy soils. These properties facilitate seedbed formation, fumigation when necessary, soil moisture control and seedling lifting. The frequent additions of inorganic nutrients and water, however, coupled with well-aerated soils produce conditions conducive to rapid OM decomposition. This process

is accelerated by the climatic conditions of the southeastern United States.

Organic materials used in OM maintenance programs include (a) those grown on-site (cover crops) and (b) those brought to the site. Although the use of cover crops is the conventional method of OM maintenance, rapid decomposition of green crops after incorporation into the soil has led to questioning of their actual value (Davey and Krause 1980).

Exogenous sources of OM have been used for many years, and currently are receiving considerable attention. A large variety of materials have been used, including peat and sawdust. Several studies have examined the influence of OM additions on seedling growth and, to a lesser extent, on soil properties (Wilde and Hull 1937, Davey 1953, Brown and Myland 1979). Relatively little emphasis has been placed on quantifying the decomposition of any organic materials applied to nursery soils.

Therefore, a series of three studies were conducted to examine the influence of several organic materials on OM levels, selected soil properties and seedling development. Peat was emphasized due to the occurrence of peat deposits in Florida. The first study consisted of operational-scale field plots testing addition of peat at three rates with or without fumigation, over a 21-month period. The second study consisted of field microplots comparing peat, sawdust, shredded cones, and sewage sludge at three rates over an 18-month period.

The third study, under laboratory conditions, compared the decomposition of the foregoing materials plus two others--bark and pulp mill waste--over a 7-month period.

The overall thrust of the investigation was to provide quantitative information on the decomposition of organic materials, especially peat, and on their effects on seedling development when applied to sandy nursery soils in Florida.

LITERATURE REVIEW

The history of the plant and soil sciences reveals that the importance of organic matter (OM) with regard to plant growth was one of the major revelations of early investigators. A chronological sequence of investigators, including Bacon, Van Helmont, Boyle, Glauber, Mayow, Woodward, de Saussure, Liebig, and Lawes and Gilbert, conducted a progressive series of trials, errors, and observations which eventually demonstrated the great influence of OM on plant growth and development (Russell 1973). The more precise description of the role of OM in plant functions has come about in the past century largely by virtue of technological advances which have improved the separation, detection, and characterization of OM components at the compound and ionic levels.

Subsequent research on the formation, composition, function and fate of soil OM has been reviewed by several authors (Waksman 1938; Kononova 1961; Schnitzer and Khan 1972, 1978; Allison 1973).

Ever since OM was shown to have such decided effects on plant growth, its maintenance has carried a position of prominence in soil management. Because decomposition is a degenerative process, the task of maintaining a given level of OM is never accomplished. Several studies have demonstrated the rapid decomposition rates of agronomic crop residues and green manures. For example, Parker (1962) showed a 65% loss of cornstalk residue when buried in the soil for 20 weeks.

Brown and Dickey (1970) reported losses of 50% in 3 months and 93% in 18 months for wheat straw buried in soil. Sain and Broadbent (1977) showed a 40% loss of buried wheat straw between November and April. More substantive reviews of the rapid decomposition of agronomic crop residues have been provided by Russell (1973) and Allison (1973).

The problems associated with OM maintenance are nowhere more appreciated than in soil-based nursery systems which produce ornamental or forest tree seedlings. The moist but well-aerated soils and frequent nutrient additions in most nurseries produce ideal conditions for microbial oxidation of organic residues. The problem is further accentuated by complete crop removal, as opposed to most agricultural crops where much of the plant remains in the field after harvest. A contemporary review of the function and maintenance of OM in forest nursery soils is presented by Davey and Krause (1980). They subdivide OM into two general fractions: (a) stable, and (b) dynamic. They point out that the stable fraction has an equilibrium level which varies with geographic location. The cooler temperatures and often the presence of finer-textured soils in the more northern nurseries result in OM equilibrium levels of 3 to 5%. In the lower coastal plain of the southeastern United States this level is often near 1%. Such geographic variation in OM equilibrium levels is discussed further by Brady (1974).

Since little can be done to significantly increase the stable OM fraction, OM maintenance programs must be directed at manipulating the dynamic fraction. For practical purposes, this fraction consists of organic materials which have not been re-synthesized into humic

substances. Methods to maintain or increase this dynamic fraction have included growing materials on-site in the form of cover crops or bringing materials to the site.

The use of cover crops has been the conventional method of OM maintenance, being practiced by 92 of 99 nurseries surveyed by Abbott and Fitch (1977). A study by Sumner and Bouton (1981) in a Georgia nursery compared several spring and fall sown cover crops. Summer crops of sorghum and pearl millet yielded 13.2 and 12.1 mt/ha, while a winter crop of crimson clover + ryegrass yielded 8.3 mt/ha. Soil organic matter content was initially 1.1% which led them to conclude that it was not possible to increase the OM content above a level of 1.4 to 1.6%, even if a rotation involving 2 years of cover cropping were practiced. Such an increase is not an unreasonable expectation, however, as suggested by Pritchett (1979). An addition of 10 mt/ha (dry weight) of cover crop is equivalent to an initial increase of 0.5% OM in the surface layer. Much of this will decompose in the first few months after incorporation. Moreover, some studies have shown that incorporation of green manures will accelerate the loss of carbon and nitrogen from the native OM (Broadbent 1948, Löhnis 1926). A general conclusion of this brief review is that substantial increases in OM may be achieved only by addition of exogenous materials.

The historical use of exogenous materials for OM maintenance was discussed by Allison (1973) and Davey and Krause (1980). The survey by Abbott and Fitch (1977) showed the most commonly used organic materials and the numbers of nurseries reporting their use as follows:

sawdust, 35; peat, 14; manure, 7; rotted bark, 5; wood chips, 3; mushroom compost, 3. Investigations on the use of sawdust have demonstrated that fresh materials may create nutritional or phytotoxic problems, but that composting renders them more useful for plant growth (Turk 1943, Allison and Anderson 1951, Davey 1953, Iyer and Morby 1979). Peat has been used extensively in northern nurseries with generally good results on plant growth (Burd 1918, Wilde and Hull 1937, Lunt 1961, Brown and Myland 1979). Manure, rotted bark and mushroom compost have been used successfully but are only locally available. Wood chips have been used to some extent but generally have been too coarse to be of immediate value as OM (Lunt 1955).

The recent emphasis on land application of municipal sewage sludge has resulted in some nurseries using the digested material directly from the treatment facility, or as a packaged product, such as "Milorganite," sold by the city of Milwaukee, Wisconsin. Several studies have examined the organic matter and nutritive value of various sludges (Gouin 1977, Sommers 1977, Magdoff and Amadon 1980). The general concern in applying sludge is the possibility of high contents of heavy metals and calcium. The latter may result in increasing pH well above that considered to be optimum for pine seedlings (5.0 to 6.0, Armson and Sadreika 1979). Additionally, since most sewage sludges have high nitrogen contents (2 to 7%), even moderate application rates may result in large leaching losses of nitrates. This can accelerate the leaching

losses of Ca, Mg and K (Raney 1960). Ultimately, application of any organic amendment should be preceded by adequate knowledge of its influences on plant growth.

Once a material has been determined to be a suitable amendment in terms of plant growth, the question of availability at a reasonable cost arises. Diminishing supplies of waste wood in recent years and competing demands have reduced availability of low cost chips and sawdust. This, coupled with their limitations as amendments, has made nursery managers search for other materials. The availability of alternate materials, however, depends on each individual nursery's situation.

An examination of organic materials available to forest nurseries in Florida reveals that peat has attractive possibilities. Peat has been used successfully in northern nurseries, as cited earlier, and has been shown to have low to moderate decomposition rates as well as having beneficial effects on plant growth (Feustel and Byers 1933). An account of the distribution and utilization of the peat resources in Florida is provided by Davis (1946). Although the major peat resource is in south Florida, a significant number of deposits occur in the northeast and north central portion of the state. Furthermore, the majority of north Florida peats are acidic in reaction. Since most of the forest nurseries in Florida are located in the northern portion of the state, the potential for using peat in these nurseries appears promising. The ability to exploit such deposits, however, rests on combinations of ownership, managerial and logistical considerations unique to each nursery.

The benefits derived from OM additions appear to be well documented. Questions of how much to apply and to what degree seedling quality will increase, however, remain largely unanswered. Until the criteria indicative of seedling quality are clearly established, the latter question cannot be answered. An answer to the first question is attainable assuming that a given level of OM is set as an objective. Optimum application rates for various materials are functions of (a) their effect on seedling growth, and (b) the rate of decomposition. Although several of the aforementioned studies evaluated the effects of organic additions on seedling growth and on decomposition under laboratory conditions (Feustel and Byers 1933, Allison 1965, Agbim et al., 1977), there is little quantitative information on decomposition rates under field conditions. Such information is required for knowledgeable decisions in formulating OM maintenance programs.

CHAPTER I
FIELD MACROPLOT STUDY WITH PEAT

Introduction

Woody materials such as sawdust, chips and bark have been used as soil amendments during the past several decades, but recently have become less available at a low cost due to more complete use in manufacturing processes, such as fuel, or for other purposes. Nursery managers are therefore searching for new alternative sources and re-evaluating the old. One such alternative is peat. Peat has been used extensively in nurseries in the Lake States, primarily because peat deposits were fairly abundant and within reasonable trucking distance to the nursery. Far less emphasis has been placed on peat as an organic amendment for nurseries in the Southeast. Several nurseries in Florida are fairly close to peat deposits making use of peat a potential alternative.

The overall hypothesis of this investigation is that pine nursery seedlings can be grown continuously in the same ground without need for alternate-year cover cropping and regular soil fumigation, provided that soil organic matter is maintained at or above its current level by appropriate additions. This study examined the utility of peat for this purpose, including its rate of decomposition, its effect on selected soil properties, and its influence--with and without soil fumigation-- on seedling growth, mycorrhizal status and incidence of charcoal root rot.

Materials and Methods

Study Area

The study was conducted at the Container Corporation of America forest tree nursery near Archer, Florida. The soil in the study compartment is classified as Millhopper sand (loamy, siliceous, hyperthermic Grossarenic Paleudult). This series consists of moderately well drained, moderately permeable soils that formed in thick beds of sandy and loamy marine sediments. Prior to clearing and grading as a nursery in 1970, the area had been successively cultivated, abandoned, and planted to slash pine (*Pinus elliottii* var. *elliottii* Engelm.). The first seedling crop was grown in 1971. Mean July and January monthly temperatures are 27° and 14° C, respectively. Annual precipitation averages 1240 mm, most of which occurs in summer and winter.

Experimental Design and Conduct

The shredded peat applied as a soil amendment was obtained from a commercial peat mine, 45 km distant. It would be classified as a medisaprist, apparently derived from grasses and sedges. It is acid, pH 4.5 (in water). Its dry weight composition is ash, 14%; C, 53.7%; N, 2.85% (3.3% ash-free basis); C/N, 18.8; CEC, 100 to 200 meq/100 g. Total elemental concentrations (ppm) are as follows: P, 160; K, 90; Ca, 1250; Mg, 415; Cu, 3; Fe, 950; Mn, 5; Zn, 3.

The experiment was established in a compartment that had been under a 1 : 1 or 1 : 2 cover crop : pine rotation for 8 years. The primary cover crop used had been pearl millet [*Pennisetum glaucum* (L.) R. Brown]. The crop immediately preceding the experiment was slash pine established after fumigation. Following experimental treatment, two additional crops of slash pine were grown successively in 1980 and 1981. Contrary to routine procedure, the experimental beds were not fumigated except as a designed treatment. With exception of this and the peat application, almost all other cultural practices--sowing, weed control, fungicide sprays, irrigation and fertilization--were identical, with routine treatment of operational slash pine beds in this compartment. The only further exception was that seedlings in the experimental area were not top-mowed late in the season.

Four rates of peat (0, 22.4, 44.8, and 67.2 dry mt/ha) with three replicates were applied to 6 x 18-m plots covering a total area of 18 x 72 m (Fig. 1-1). The intent of the additions (P_1, P_2, P_3, respectively) was to raise soil organic matter (OM) levels by approximately 1, 2, and 3% above the native level of 1%. The treatments were arranged in a completely randomized design. Each plot was three standard nursery beds in width, but measurements were confined to a 4 x 16-m area in each plot. The 1-m wide border around the sample area served as a buffer against soil mixing during nursery operations. A subplot, 6-m long, in each central bed (per plot) was fumigated with MC-2

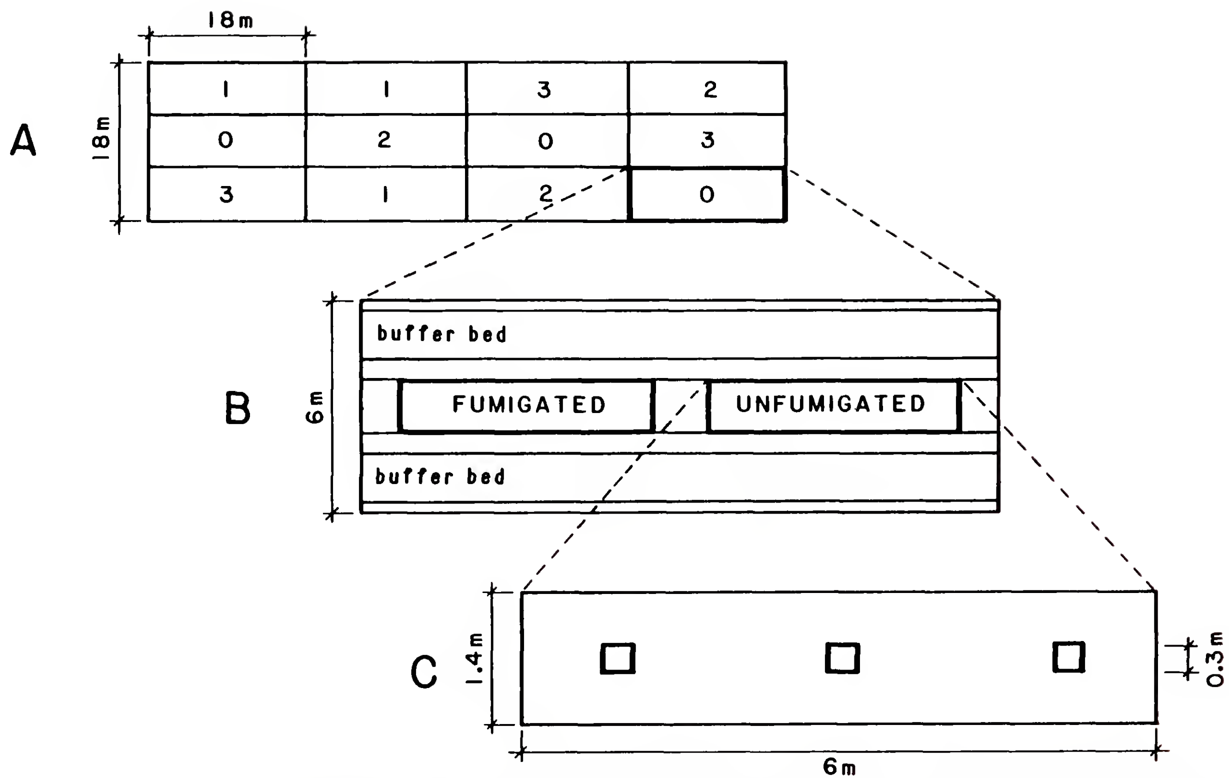

Figure 1-1. Field plot arrangement showing random locations of treatment (A), fumigation subplots (B), and 0.1 m^2 seedling sample quadrats (C). 1, 2, 3 = 22.4, 44.8, and 67.2 mt/ha, respectively. Fumigant application was 448 kg/ha MC-2.

(98% methyl bromide, 2% chloropycrin) (Fig. 1-1) after peat application (1980) or tillage (1981), and 1 week prior to sowing. The fumigated plots were in the same location in both years.

Peat was applied with a front-end loader in April 1980, spread uniformly by hand, and incorporated to 20 cm using a mould-board plow and repeated discing. Seed was sown in May 1980 and 1981 to achieve a postemergent density of 28 stems/0.1 m^2. The fertilizer regime consisted of pre-plant applications of 672 kg/ha 5-10-20 in 1980 and 0-10-20 in 1981, followed by four maintenance applications of 168 kg/ha 10-10-10 in 1980 and only two in 1981. The postemergence fertilizers were broadcast as granular and liquid in 1980 and 1981, respectively. All fertilizer materials had a micronutrient mix of Mn (.2%), Fe (.1%), Zn (.05%), B (.05%), and Mg (.06%). The lower amounts of fertilizer nutrients supplied in 1981 apparently account for the smaller total dry matter production in that year.

Sampling Scheme

Soil samples were taken before and after peat application, then subsequently at 3-month intervals for 21 months. At each sample period, three composite samples, each consisting of 15 cores, 2.5-cm diameter x 20-cm deep, were taken randomly from each replicate plot. Soil from the fumigated subplots and the interbed area was not included in the samples.

Seedling samples were taken on three 0.1 m^2 quadrats in each fumigated and unfumigated subplot (Fig. 1-1) at the end of the 1980 and 1981 growing seasons. Samples were taken by pressing a steel

frame (0.1 m^2 x 15-cm deep) into the soil and hand lifting all seedlings within the frame. An additional 10 seedlings were randomly sampled from each fumigated and unfumigated subplot for a qualitative evaluation of charcoal root rot infection.

Laboratory and Chemical Analyses

Soil samples were air-dried and sieved to pass a 2-mm mesh. Organic matter was determined by loss-on-ignition after combustion of a 25- to 30-gram sample at 550° C for 8 hours. Ash content of the peat was determined similarly. Organic C was determined on the peat by the Walkley-Black wet oxidation technique (Jackson 1958). Soil pH was measured in a 2 : 1 distilled water-to-soil ratio using a standard glass electrode. Total soil N was determined by the micro-Kjeldahl method (Bremner 1965). Soil samples were extracted with a double acid solution (0.05 N HCL + 0.025 N H_2SO_4, Page et al., 1965); K, Ca, Mg, Cu, Mn and Zn in the extract were determined by atomic absorption spectrophotometry, and P by a Technicon Autoanalyzer II (Technicon Industrial Systems 1978). Peat and tissue samples were dry ashed and digested in 6 N HCL; K, Ca, Mg, Cu, Mn, and Zn were determined by atomic absorption spectrophotometry. Nitrogen and P in these materials were determined colorimetrically on a Technicon Autoanalyzer II following block digestion (Technicon Industrial Systems 1978).

Seedlings were measured individually for height and stem diameter, and collectively (by 0.1 m^2 quadrats) for oven dry weights. The

percentage of mycorrhizal short roots on five seedlings was estimated after a visual scan of the root systems at 7 x magnification.[1] A short root was considered mycorrhizal if it had a hyphal mantle. Incidence of charcoal root rot was determined by a visual analysis of external infection symptoms[2] on the 10 seedlings sampled for this purpose.

Statistical Analysis

Data analyses were conducted using general linear model procedures in the Statistical Analysis System (Barr et al., 1979). The change in soil organic matter over time was characterized by equations generated from individual plot means. Mean soil pH values within sample periods and mean values for the seedling physical and chemical variables were compared using Duncan's multiple range test at a = .05 (Snedecor and Cochran 1967). The analysis of variance designs used for comparisons among treatments are presented in Table 1-1.

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1 The technique and sample number were suggested by Dr. D.H. Marx, Director, Institute for Mycorrhizal Research and Development, USDA Forest Service, Athens, GA.

2 This procedure was conducted under the guidance of Dr. E.L. Barnard, Forest Pathologist, Florida Division of Forestry, Gainesville, FL.

Table 1-1. Analysis of variance designs used for treatment comparisons.

Variable	Source of variation	d.f.	Variable	Source of variation	d.f.
OM	treatment	3	Seedling data	treatment	3
	rep (treatment)	8	-error a-	rep (treatment)	8
	time	7		fumigation	1
	time x treatment	21		fumigation x treatment	3
	time x rep (treatment)	56	-error b-	fumigation x rep (treatment)	8
	residual	480		residual	48
	total	575		total	71
pH	treatment	3	Soil data	treatment	3
	rep (treatment)	8	-error a-	rep (treatment)	8
	time	7		time	2
	time x treatment	21		time x treatment	6
	time x rep (treatment)	56	-error b-	time x rep (treatment	16
	residual	192		total	35
	total	287			

Results and Discussion

Peat Decomposition

Statistical analyses showed that the decline in OM over a 21-month period did not follow a common pattern for the four levels of peat application treatment, thus requiring each treatment to be evaluated separately. The data were examined by generating equations that described the mean course of decomposition (Fig. 1-2). Analyses showed that the control and Peat 1 (22.4 mt/ha) data were neither linear nor quadratic, and are thus best described by horizontal lines. Both the Peat 2 (44.8 mt/ha) and Peat 3 (67.2 mt/ha) levels showed only linear trends.

OM percentages measured immediately following peat application were lower than expected from the amounts applied. The expected and observed percentages were 1.64 and 1.43, 2.29 and 1.95, and 2.94 and 2.48 for Peat 1, 2, and 3, respectively, or about a 15% reduction. Two possible causes of this discrepancy are (a) the peat application may have been less than estimated, or (b) the plow-down process placed some peat below the 20-cm sample zone. In any case, the discrepancy does not affect the hypothesis or results of the study.

The last consequential organic addition to the study site had been the cover crop plowed down 14 months previously. Hence, the indigenous soil organic matter at the beginning of the study was assumed to be relatively stable. It proved remarkably so, with the

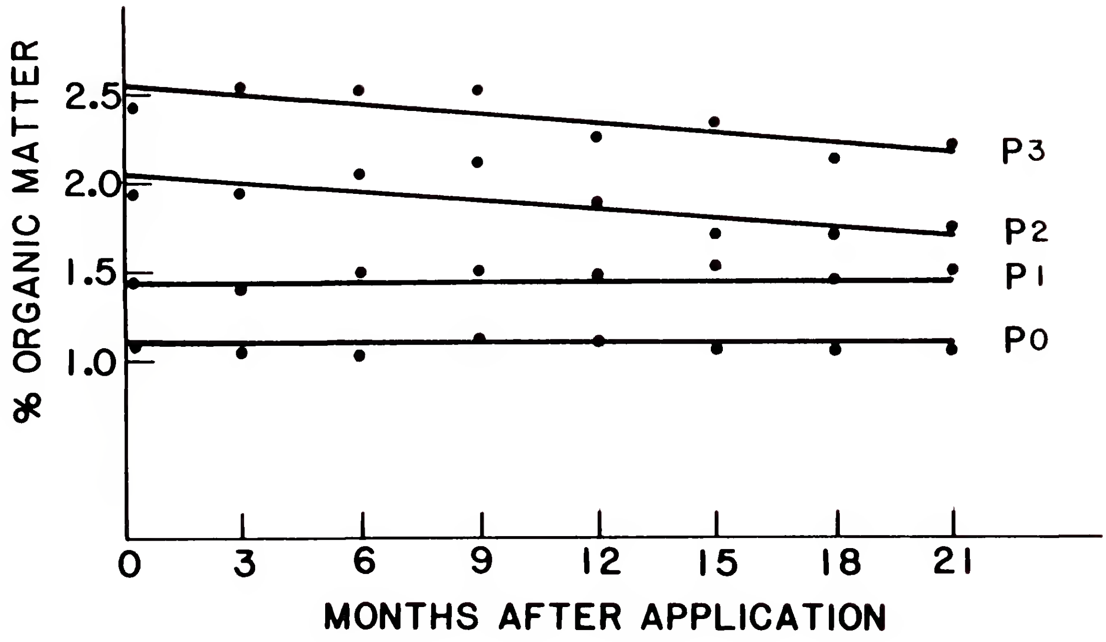

Figure 1-2. Organic matter decomposition in an unfumigated nursery soil amended with peat at three rates (1, 2, 3). Points are observed values. Regressions of best-fit lines and correlations are as follows:

Peat 2, $y = 2.04 - 0.015\ T$, .21; Peat 3, $y = 2.57 - 0.02\ T$, .23 .

control treatment showing no measurable decrease in OM over the 21-month period (Fig. 1-2). Likewise, the higher total OM content of the Peat 1 treatment appeared constant, presumably because cumulative decomposition of the added peat was too small to be detected against background variability of both soil and intermixed peat. In contrast, the Peat 2 and 3 treatments display the expected cumulative decrease despite high variability (Fig. 1-2). The slopes appear linear, with the higher rate having the steeper slope. This indicates that decomposition rate is proportional to application rate. Thus, optimizing residence time of peat in soil may be best achieved by smaller applications at frequent intervals rather than by less frequent large additions.

The latter is consistent with the findings of Lund and Doss (1980). They observed that organic matter content of plots treated with 90, 180 or 270 mt/ha (wet weight) of dairy manure all reached a common level in approximately 70 months. Such a time requirement obviously must vary with both the soil environment and composition of the added organic material. Perhaps by coincidence, however, the projected slopes of the Peat 2 and 3 treatments would indicate return to the level of the control in 64 and 74 months, respectively.

The latter extrapolation is highly speculative but emphasizes the moderate loss rate. In contrast, a hypothetical curve used as an illustration by Davey and Krause (1980) proposed that two-thirds of a 20 mt/ha addition of peat would be lost in the first year. A further comparison is with the loss rates revealed by subsidence studies in cultivated peat land in south Florida (Knipling et al., 1970).

Carbon dioxide evolution from each 1% OM (ash free amounted to 1.58 mt/ha $\cdot$ yr^{-1}. Calculated loss rate from the Peat 2 treatment in the present study is roughly similar, 1.65 mt/ha $\cdot$ yr^{-1} for each 1% OM initially added as peat (i.e., exclusive of native soil OM).

In the present study, as with most field studies, variability limits precise determination, as is illustrated by the scatter of observed OM values around the generated lines in Figure 1-2. Spatial variability was reduced by intensive soil sampling. The influence of other sources of soil variability, however, including seedling lifting, discing, bed reestablishment and seasonal differences in decomposition rates can neither be eliminated nor accounted for.

Although decomposition of the peat used in this study is relatively slow, its high N content (3.31% on an ash-free basis) and narrow C/N ratio nevertheless make it a major source of N for plant growth. Moreover, this N becomes available gradually, i.e., it is a "slow release" N, which accords well with the year long growth period of pine seedlings. Thus, assuming net N mineralization to have been proportional to decomposition, i.e., no further reduction in C/N ratio, the Peat 2 and 3 treatments released approximately 179 and 257 kg/ha N, respectively, over the 21-month period. These amounts compare with 141 kg/ha inorganic N added by routine fertilization practice to the two seedling crops grown in this period. Actual rates of N mineralization from added peat are yet to be determined by specific studies. It is clear, however, that any comparison of peat with other organic materials must consider N supply as well as contribution to soil OM.

Effects on Soil Chemical Properties

Soil reaction. The mean pH values at the various sample periods are presented in Table 1-2. Because rainfall, intermittent fertilizer additions and irrigation with high Ca water affect soil reaction, the most meaningful analysis is comparison among treatments at the same sample date. The immediate effect of peat application on soil pH reflects its own low pH, 4.5, and the very low exchange capacity of the mineral soil. At the time of application, each 1% increase in OM decreased pH by .3 unit. Twenty-one months after application, the buffering effect was even more pronounced, with pH decreasing .6 unit for each 1% OM.

A range in pH values from 5 to 6 is considered satisfactory for most coniferous species (Armson and Sadreika 1979). In this study, pH values in the unamended plots showed relatively high seasonal fluctuations (5.5 - 6.1) with an overall mean pH near 6. In contrast, the Peat 1, 2 and 3 treatments showed slightly less fluctuation and maintained overall pH values of 5.5, 5.3 and 5.1, respectively. Additional measurements of soil pH in the study plots will determine the persistence of the peat treatment effects.

Soil nutrient status. Statistical analyses of chemical data from samples of unfumigated soil taken initially and at the end of the first and second growing seasons show significant effects due to treatment and sample time, with no interaction (Table 1-3). Peat treatments increased N and Mn levels; the N was obviously from the peat itself, and the Mn increase was probably due to increased Mn solubility at the lower pH levels after peat additions. The changes in nutrient status over time

Table 1-2. Soil reaction as influenced by peat amendment.

Treatment	Initial	Months after application							
		0	3	6	9	12	15	18	21
	----------pH----------								
Control[1/]	5.9 [2/]	5.6 a[3/]	5.5 a	5.7 a	5.5 a	5.6 a	6.1 a	5.8 a	5.8 a
Peat 1	6.0	5.5 a	5.3 b	5.7 a	5.5 a	5.4 b	5.8 ab	5.7 a	5.5 b
Peat 2	6.0	5.3 b	5.2 b	5.3 b	5.0 b	5.3 b	5.7 b	5.5 b	5.3 b
Peat 3	6.0	5.2 b	4.9 c	5.1 b	4.9 b	5.2 c	5.4 c	5.4 b	5.1 c

1/ Peat 1, 2, 3 refer to application rates.

2/ Two probable causes of the lower pH in the control plots after peat application are slight contamination with peat from adjacent treated plots during the incorporation process and the pre-plant fertilizer application. A slight increase in OM was also observed in the control plots after peat incorporation.

3/ Values in each column which have the same letter are not significantly different (Duncan's, a = .05).

Table 1-3. Soil nutrient status as influenced by peat application and time of sampling.

	Nutrient[1]						
	N	P	K	Ca	Mg	Mn	Zn
	ppm						
Treatment[2]							
Control	209 a[3]	48	24	149	8	4.7 a	.44
Peat 1	367 ab	43	22	194	11	5.2 ab	.43
Peat 2	518 bc	44	24	192	10	5.6 b	.44
Peat 3	695 c	40	24	180	11	5.6 b	.45
Months after application[4]							
0	441	40 a	32 a	192 ab	12 a	5.0 a	.36 a
9	480	40 a	20 b	140 a	7 b	5.0 a	.38 a
21	421	51 b	18 b	205 b	11 a	5.8 b	.60 b

[1] N = total. Other elements extractable by .025 N H_2SO_4 + .05 N HCl.

[2] Averaged over samples taken initially, and 9 and 12 months after peat application.

[3] Values in subcolumns with the same letter or no letter are not significantly different (Duncan's, a = .05).

[4] Averaged over peat treatments in unfumigated soil.

reflect management practices. Accumulations of P, Mn and Zn are from inorganic fertilizer additions. Losses of K and Ca in the first year may be due in part to crop uptake, but most likely are due to leaching with nitrates mineralized from the peat.

A comparison of nutrient status in fumigated and unfumigated soil 21 months after peat application showed significant effects of both peat and fumigation without significant interaction (Table 1-4). The difference in peat treatments follows a similar pattern as discussed previously (Table 1-3). The unfumigated plots had lower P and Zn values and higher Mn values than the fumigated plots. The latter may be explained by greater uptake of Mn by seedlings grown in the fumigated plots as compared to seedlings grown in the unfumigated plots (Table 1-9). The differences in P and Zn values cannot be accounted for.

The lowering of pH by peat addition would have some influence on nutrient availability. Additionally, peat influences soil nutrient status by its own elemental contribution and by absorption of fertilizer nutrients. Krause[1] has shown the latter effect to be of little consequence. Likewise, with the exception of nitrogen, this peat contained low amounts of most nutrients. These facts are consistent with the small differences among the peat rates in Tables 1-3 and 1-4. Comparison of seedling nutrient contents, however, as discussed in a later section, shows that seedlings from the peat-amended plots contained significantly greater amounts of most nutrients than those in control plots. The apparent stability of soil nutrient levels coupled with greater nutrient removal

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[1] Krause, unpublished data in Davey and Krause (1980).

Table 1-4. Soil nutrient status after 21 months as influenced by peat application averaged across fumigation, and by fumigation[1] averaged across all peat rates.

Treatment	Nutrient[2]						
	N	P	K	Ca	Mg	Mn	Zn
	ppm						
Control	192 a[3]	54 a	19	171	9	4.5 a	.57
Peat 1	379 ab	49 ab	19	208	14	5.1 ab	.67
Peat 2	487 bc	46 b	19	227	11	5.8 b	.65
Peat 3	656 c	44 b	18	206	12	6.0 b	.67
Fumigated	436	51 a	19	202	12	4.9 a	.69 a
Unfumigated	420	46 b	18	205	11	5.8 b	.60 b

1/ Second fumigation with 448 kg/ha MC-2 9 months previously.

2/ N = total. Other elements extractable by .025 N H_2SO_4 + .05 N HCl.

3/ Values in subcolumns with the same letter or no letter are not significantly different (Duncan's, a = .05).

from the peat-amended plots is circumstantial evidence that peat improved the soil fertility status with respect to meeting crop needs.

These results further demonstrate that additions of OM, in this case acid peat, in these sandy, poorly-buffered soils can have a significant effect on conditions for plant growth.

Effects on Seedling Development

Physical parameters. Seedling development was significantly influenced by both peat and fumigation, but without an interaction effect.

Shoot height was the only physical parameter that consistently increased in response to peat application (Table 1-5). This is of little practical interest since operational seedlings often must be mowed during the latter part of the season to avoid excess height. More notable are the stem diameter and dry matter values, which, in both years tended to increase with peat application, although the differences were not statistically significant. The difference in total dry matter between the crops is due largely to lower amounts of fertilizer applied in the second year (see Experimental Design and Conduct).

The effects of fumigation were more apparent, with all physical parameters being greater for seedlings grown in fumigated soil in both years (Table 1-6). Seeds sown in the fumigated plots germinated slightly sooner and had more rapid cotyledonary growth than seedlings in unfumigated soil, possibly due to nutrient release and pathogen control. Presumably this early advantage in development was carried throughout the growing season.

Table 1-5. Physical parameters of two successive crops of slash pine seedlings as influenced by peat amendment averaged across fumigation treatment.

Treatment	Seedling number	Height	Stem dia.	Oven-dry weight shoot	Oven-dry weight root	Dry matter	Shoot/root ratio
	no/m^2	cm	mm	--------	g/m^2	--------	
1980 Crop							
Control	210	23.5 a[1/]	5.6	910	280	1190	3.3
Peat 1	220	23.9 a	5.4	890	250	1150	3.6
Peat 2	190	25.9 b	6.3	1060	300	1360	3.6
Peat 3	200	26.4 b	6.0	1070	300	1370	3.6
1981 Crop							
Control	320	21.1 a	4.0	630[3/]	180	810	3.5
Peat 1	270	22.7 b	4.4	700	180	890	3.9
Peat 2	270	24.0 b	4.6	720	190	910	3.8
Peat 3	260	23.3 b	4.6	710	190	900	3.7

1/ Values in columns (within crop year) with the same letter or no letter are not significantly different (Duncan's, a = .05).

Table 1-6. Physical parameters of two successive crops of slash pine seedlings as influenced by fumigation [1/] averaged across all peat treatments.

Treatment	Seedling number	Height	Stem dia.	Oven-dry weight shoot	Oven-dry weight root	Dry matter	Shoot/root ratio
	no/m²	*cm*	*mm*	--------*g/m²*		---------	
1980 Crop							
Fumigated	200	26.0 a[2/]	6.2 a	1070 a	310 a	1380 a	3.5
Unfumigated	210	23.8 b	5.4 b	890 b	260 b	1150 b	3.5
1981 Crop							
Fumigated	300 a	24.2 a	4.6 a	770 a	210 a	980 a	3.6
Unfumigated	260 a	21.4 b	4.2 b	610 b	160 b	770 b	3.8

[1/] Fumigation with 448 kg/ha MC-2.

[2/] Values in subcolumns with the same letter or no letter are not significantly different (Duncan's, a = .05).

Chemical parameters. Chemical analyses of the 1981 crop show that peat treatment had no effect on concentrations of P, K, Ca, Mg, Cu and Zn (Table 1-7), but that concentrations of N and Mn were greater in seedlings grown in peat-amended soil (Fig. 1-3). The increased N levels may be due to greater retention of NH_4-N by the higher CEC, and certainly by additional N mineralized from the peat during decomposition. The increased Mn levels are associated with increased Mn solubility at the lower soil reaction in the peat treatments (Table 1-2).

The effects of fumigation were evident, with N, P, K, Ca, Cu, and Zn concentrations being greater in seedlings grown in unfumigated soil (Fig. 1-4). Total elemental contents of N, P (Fig. 1-5), Mg, Mn, and Zn (Table 1-8), as calculated from concentration and shoot weight/ unit area, were greater in seedlings grown in peat-amended soil. Coupled with the fact that neither dry matter production nor extractable soil nutrient concentrations were generally affected by peat treatments, this indicates that peat enhanced nutrient uptake by the seedlings.

The larger seedlings grown in fumigated soil had significantly higher total contents of K, Mg, Cu, and Mn (Table 1-9), although concentrations were generally lower than those from the unfumigated treatments (Fig. 1-4). In contrast, the N content was greater in seedlings grown in unfumigated soil (Table 1-9), despite the fact that seedlings from the fumigated soil were heavier (Table 1-6).

Table 1-7. Element concentrations of slash pine seedling shoots grown in 1981 as influenced by peat amendment averaged across fumigation treatment.

Treatment	Tissue concentration					
	P	K	Ca	Mg	Cu	Zn
	%				ppm	
Control	.15[1/]	.76	.51	.10	5.1	38
Peat 1	.16	.76	.48	.11	5.2	45
Peat 2	.17	.77	.50	.10	5.4	43
Peat 3	.17	.72	.49	.10	4.9	41

1/ Values in columns are not significantly different (Duncan's, a = .05).

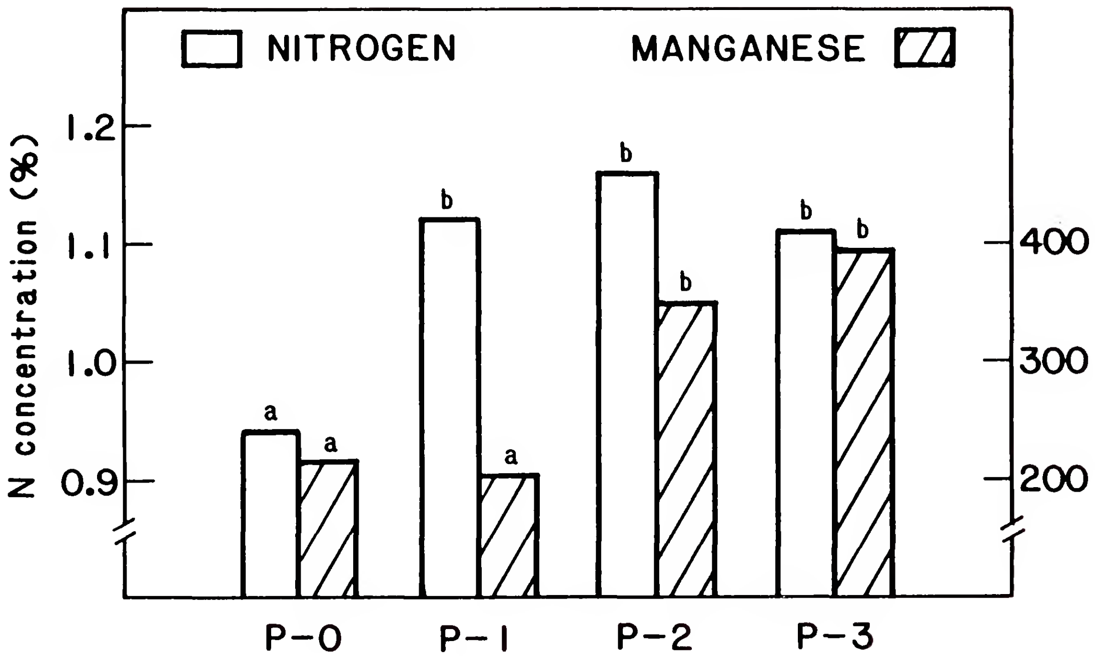

Figure 1-3. Nitrogen and Mn concentrations in slash pine seedling shoots grown in 1981 as influenced by peat amendment averaged across fumigation treatment. P-1, 2, 3 refer to rates of application in 1980. Values with the same letter (by element) are not significantly different (Duncan's, a = .05).

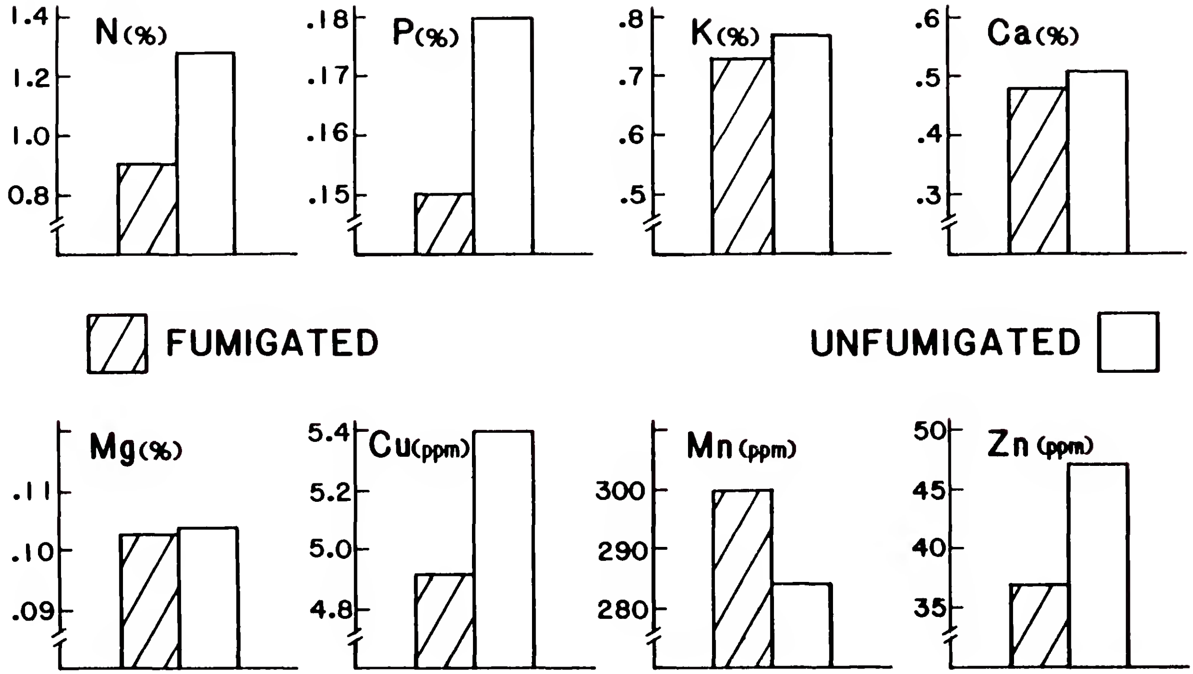

Figure 1-4. Elemental concentrations of slash pine seedling shoots grown in 1981 as influenced by fumigation (448 kg/ha MC-2) averaged across peat treatment. Differences are significant with the exception of Mg and Mn (Duncan's, a = .05).

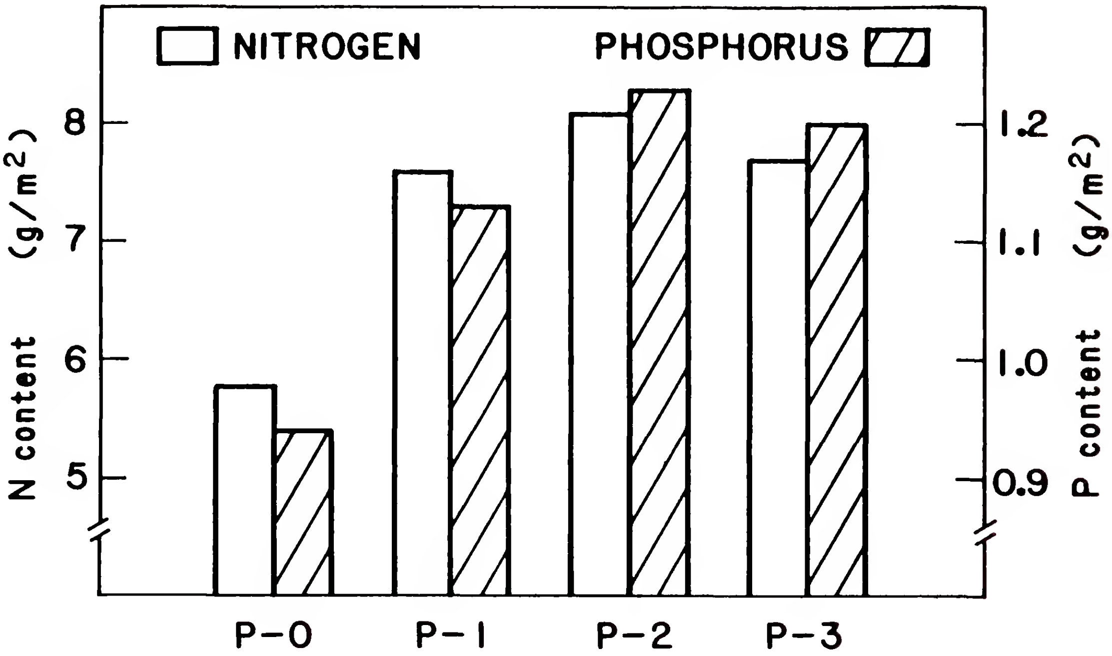

Figure 1-5. Nitrogen and P contents of slash pine seedling shoots grown in 1981 as influenced by peat amendment averaged across fumigation treatment. P-1, 2, 3 refer to application rates. N and P contents in the control seedlings are significantly less than in the treated seedlings (Duncan's, a = .05).

Table 1-8. Elemental contents of slash pine seedling shoots grown in 1981 as influenced by peat amendment averaged across fumigation treatment.

Treatment	Tissue content					
	K	Ca	Mg	Cu	Mn	Zn
	-------- g/m^2	--	-----	------ mg/m^2	-------	
Control	4.75[1/]	3.17	0.59 a	3.2	140 a	23 a
Peat 1	5.29	3.39	0.78 b	3.6	140 a	31 b
Peat 2	5.45	3.55	0.74 b	3.8	260 b	31 b
Peat 3	5.09	3.39	0.72 b	3.5	280 b	28 b

[1/] Values in columns with the same letter or no letter are not significantly different (Duncan's, a = .05).

Table 1-9. Elemental contents of slash pine seedling shoots grown in 1981 as influenced by fumigation[1/] averaged across all peat treatments.

Treatment	Tissue content							
	N	P	K	Ca	Mg	Cu	Mn	Zn
	------------- g/m^2 --------------					-----mg/m^2 ------		
Fumigated	6.9 a	1.14[2/]	5.59 a	3.67	0.79 a	3.8 a	240 a	28
Unfumigated	7.7 b	1.11	4.71 b	3.08	0.63 b	3.3 b	170 b	28

1/ Fumigation with 448 kg/ha MC-2.

2/ Values in columns with the same letter or no letter are not significantly different (Duncan's, a = .05).

Thus, the compensatory value of peat additions, particularly for N-nutrition, becomes more apparent. A comparison of N contents of seedlings[1] grown in unfumigated soil with amount of N applied in fertilizer showed that, in both years, more N was taken up by the crop than was applied as inorganic fertilizer. The difference was made up by N mineralized from organic matter. Assuming uptake of 80% of the fertilizer-N, which is liberal, and no appreciable atmospheric inputs, seedlings grown in soil without peat addition received 28 and 66% of their tissue-N in 1980 and 1981, respectively, from native OM and a small fraction of peat pulled into the plots during tillage. In contrast, seedlings grown in unfumigated soil with peat addition obtained 44 and 71% of the tissue-N in 1980 and 1981, respectively, from the peat and native OM. As discussed previously, the peat decomposition data indicate that the Peat 2 and 3 treatments released approximately 179 and 257 kg/ha N over the 21-month period. Presumably some N was mineralized from the Peat 1 treatment as well. This clearly demonstrates the N-nutritional advantages provided by peat additions.

Effects on Mycorrhizae and Incidence of Charcoal Root Rot

An additional interest of this study was the effect of peat and fumigation treatments on mycorrhizal infection and incidence of charcoal root rot (CRR). As shown in Table 1-10, mycorrhizal infection was greater in the unfumigated soil than in the fumigated soil in both years. Mycorrhizal infection was also greater in peat amended than in unamended soil, notably so in 1980.

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[1] Estimates of N concentration in the shoots of the 1980 crop and roots of both crops made from analyses not cited here.

Table 1-10. Ectomycorrhizal infection as influenced by peat addition and fumigation.[1/]

Treatment	1980 unfumigated	1980 fumigated	1981 unfumigated	1981 fumigated
	------------ % short roots infected ------------			
Control	34	9	34	14
Peat 1	39	13	39	21
Peat 2	58	9	35	20
Peat 3	60	31	40	15

[1/] Fumigated each year with 448 kg/ha MC-2.

This indicates that natural repopulation of the fumigated soil with mycorrhizal fungi did not occur rapidly and was facilitated by peat. The latter point suggests that artificial inoculation of seed beds with mycorrhizal fungi may be more successful in soils amended with peat.

Inspection of root samples taken from the 1980 and 1981 crop showed no visual symptoms of CRR in any treatment.

Annual fumigation is used routinely in many lower coastal plain nurseries to avoid or control root-rot diseases, especially CRR caused by *Macrophomina phaseolina* tassi (Goid.) (Seymour and Cordell 1979). This is a costly and time consuming operation which also temporarily reduces or eliminates mycorrhizal fungi and organisms responsible for nitrogen mineralization and nitrification. It may be speculated that increasing soil OM levels would provide a substrate to support a larger and more diverse microbial population, which may give beneficial organisms a competitive advantage over pathogenic organisms. The higher OM levels may also facilitate production of seedlings with improved physiological quality and greater resistance to pathogenic infection. Thus, continued observations from unfumigated beds in the study area may provide additional evidence on the influence of organic matter on CRR.

In summary, the use of peat as an organic matter amendment in southern forest nurseries has decided benefits. These include pH buffering capacity, improved soil physical conditions, and improved soil fertility conditions--especially with regard to nitrogen. Decomposition rates are lower than anticipated, which would reduce annual costs associated with OM maintenance. In Florida at least, peat deposits occur in proximity to many nurseries, increasing the feasibility of use.

CHAPTER II
FIELD MICROPLOT STUDY WITH VARIOUS ORGANIC MATERIALS

Introduction

Maintenance of organic matter in forest tree nurseries is an old problem with no new solutions. In an attempt to maintain existing levels, nursery managers currently use cover crops, exogenous organic materials or often a combination of both (Davey and Krause 1980).

The declining availability at low costs of conventional amendments such as sawdust, wood chips and bark prompts a search for alternate sources of organic materials. Once a grower locates an adequate supply of a promising material, pragmatic questions arise concerning application rates, decomposition rate or residence time, and effects on seedling and soil chemical properties.

Full-scale field tests of various materials consume space and effort, whereas greenhouse pot trials are subject to regimes of soil, temperature, leaching and moisture quite different than those of the field. Accordingly, a method of microplot field trials was designed to study both the value of such a procedure and the performance of four common organic amendments applied at three rates. The questions of interest were decomposition rates, effects on selected soil properties, seedling growth, mycorrhizal development, and incidence of charcoal root rot.

Materials and Methods

Study Area

This experiment was conducted at the same nursery as the field study (Ch. 1) and was installed in a 14-m section of a buffer bed in a control plot of that study (Fig. 2-1).

Experimental Design and Conduct

The materials tested were peat, 20-year-old pine sawdust from a large pile exposed to normal weathering, municipal sewage sludge, and shredded pine cones. The peat was obtained from the same source as in the prior study (Ch. 1). Activated sewage sludge was obtained from drying beds at the University of Florida waste treatment facility. Sawdust and cones were obtained from the St. Regis Paper Company nursery near Lee, Florida. The cone residue (principally from slash and loblolly pine) was from a seed extractory located at the nursery. The application rates tested were 22.4, 44.8, and 89.6 mt/ha (dry weight), which would approximate 1, 2, and 4% increases over the native OM level. The actual increases were generally lower than expected due presumably to greater than recognized variability in moisture and ash contents of the materials, but also to mixture with greater soil weight than calculated. The chemical characteristics and particle size distribution of the materials used are listed in Table 2-1.

The microplots consisted of plastic buckets 3-mm thick, 30-cm diameter, and 35-cm deep (Fig. 2-1). To insure natural soil water flux, approximately 60% of the surface area of the sides and bottom was perforated by 5-cm diameter holes.

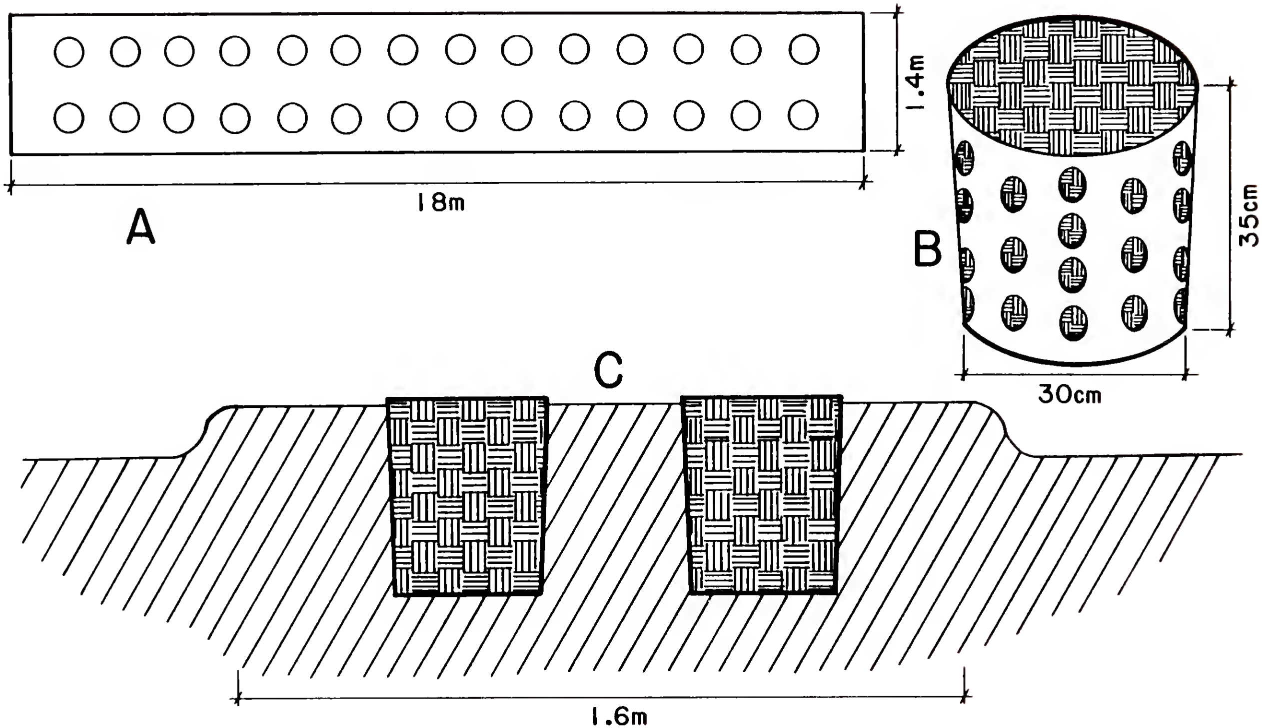


Figure 2-1. Bucket microplot location (A), microplot with soil + organic mixture (B), and the cross section of nursery bed with microplots in place (C).

Table 2-1. Chemical characteristics and particle size distribution of four organic materials used as nursery soil amendments.[1/]

Material	pH	Ash	C	N	C/N	P	K	Ca	Mg	Cu	Mn	Zn	% within each size fraction				
													<0.5 mm	0.5-1.0	1.0-2.0	2.0-6.0	>6.0
		---- % ----				---------- ppm ----------							---------- % ----------				
Peat	4.5	14	53.7	2.65	18.8	160	90	1250	415	3	5	2	14	15	20	38	12
Sludge	6.7	24	42.7	5.69	7.5	23900	2750	15500	4690	450	84	1249	7	6	8	34	44
Cones	6.2	1	56.5	0.30	188.3	215	3400	225	405	3	28	14	9	12	18	35	25
Sawdust	4.5	4	61.6	0.19	342.2	25	55	325	70	3	9	4	9	13	35	37	6

[1/] See Table 2-3 for characteristics of the nursery soil with which amendments were mixed.

Several cubic meters of unfumigated topsoil from an area adjacent to the study were piled and mixed repeatedly with a front-end loader and tractor. For each treatment, three buckets of soil were mixed in a portable cement mixer with an appropriate amount of organic material. Samples for analysis were removed; then two buckets (replicates) were filled with the mixture, and the remainder discarded. A total of 28 buckets were prepared representing 4 materials x 3 rates x 2 replicates + 4 controls. Treatments were arranged in a completely random fashion. The microplots were buried to the rim in the nursery bed (Fig. 2-1) and the surrounding soil compacted around them. The buckets were sturdy enough to withstand removal and replacement for successive crops.

In the first year, 1980, 2-week-old slash pine (*Pinus elliottii* var. *elliottii* Engelm.) seedlings were transplanted immediately after installation in mid-June. In 1981, the plots were in place when the entire bed was sown by the normal operating practice on May 1. Subsequently, seedlings received the normal operational watering, fertilization, fungicide treatments and weed control as described in Chapter 1, excepting no addition of pre-plant fertilizer. The buckets were lifted at time of harvest and the soil + organic matter mixtures were stored between late February and mid-April 1981 in plastic bags in an open nursery shed.

Sampling Scheme

Bulk soil samples were taken before and after the organic matter additions and composite samples at 3-month intervals, including the time between crops. Each composite sample consisted of four cores, 2.5 cm diameter by 30-cm deep, from each bucket.

At harvest, the soil mixture in each microplot was passed through 6-mm hardware cloth to remove all roots. Organic fragments larger than 6 mm were returned to the soil mixture. The galvanized hardware cloth increased extractable zinc contents as will appear later.

It was assumed that as many roots grew into the plots from external seedlings as grew out of the plots from internal seedlings, and hence root weights represented production by the seedlings in the bucket. This assumption was not valid when the seedling density within the plot was much lower than outside density as happened with the sludge treatments in 1980.

Analyses

Soil and plant samples were processed and analyzed as described in Chapter 1. Organic particles greater than 2 mm were kept with the soil sample. Mycorrhizal infection and incidence of charcoal root rot were assessed on five seedlings in each microplot by the procedures described in Chapter 1.

Likewise, the statistical analyses followed the procedures described in Chapter 1. The analysis of variance designs used for comparisons among treatments are presented in Table 2-2.

Table 2-2. Analysis of variance designs used for comparisons among treatments.

Variable	Source of variation	d.f.	Variable	Source of variation	d.f.
Organic matter	treatment	12	pH	treatment	12
(error a)	rep (treatment)	15	(error a)	rep (treatment)	15
	time	5		time	5
	time x treatment	60		time x treatment	60
(error b)	time x rep (treatment)	75	(error b)	time x rep (treatment)	75
	subsample error	336		total	167
	total	503			
Seedling and soil data	treatment	12	Treatment components	material	3
(error)	rep (treatment)	15		rate	2
	total	27		material x rate	6
				control	1
				total	12

Results and Discussion

Decomposition

The patterns of decomposition for the various materials and rates are described by linear regression equations (Fig. 2-2). The high r^2 values (> .90) indicated that the overall course of decomposition is linear despite seasonal variations in soil temperature and the disturbance incident to seedling harvest and reestablishment.

After 18 months, the peat treatments had lost 62, 51 and 51% of the amounts applied at the 1, 2, and 4% rates, respectively ("loss" in this discussion refers only to organic substance). Thus, the decomposition rate was much more rapid than in the field macroplot study (Ch. 1) where the 1, 2, and 3% treatments lost 0, 21, and 19% of the amounts applied. Possible reasons for the difference between the two studies are discussed later. The respective similarity in loss rate from the two higher applications within both studies, however, confirms that decomposition rate is roughly proportional to the amount added when this exceeds 1%. Linear extrapolation of the regressions in Figure 2-2 indicates that OM levels of the 1, 2, and 4% peat treatments would reach that of the control (1.3%) in 29, 35, and 35 months, respectively. In actuality, accumulation of a resistant fraction of OM likely would render the approach to the control level asymptotic.

At the end of 18 months, the sludge treatments had lost 51, 54, and 44%, respectively, of the organic content added at the 1, 2, and 4% rates. These values would suggest that the sludge was more resistant

Figure 2-2. Organic matter decomposition in a nursery soil amended with four organic materials at three rates. Points are observed values of best-fit lines. Regression equations of best-fit lines and correlations are as follows:

$\text{Peat } 1 = 2.39 - .038\,T,\ r^2 = .93$; $\text{Peat } 2 = 3.14 - .052\,T,\ r^2 = .95$;

$\text{Peat } 4 = 4.43 - .089\,T,\ r^2 = .91$; $\text{Sludge } 1 = 1.95 - .019\,T,\ r^2 = .94$;

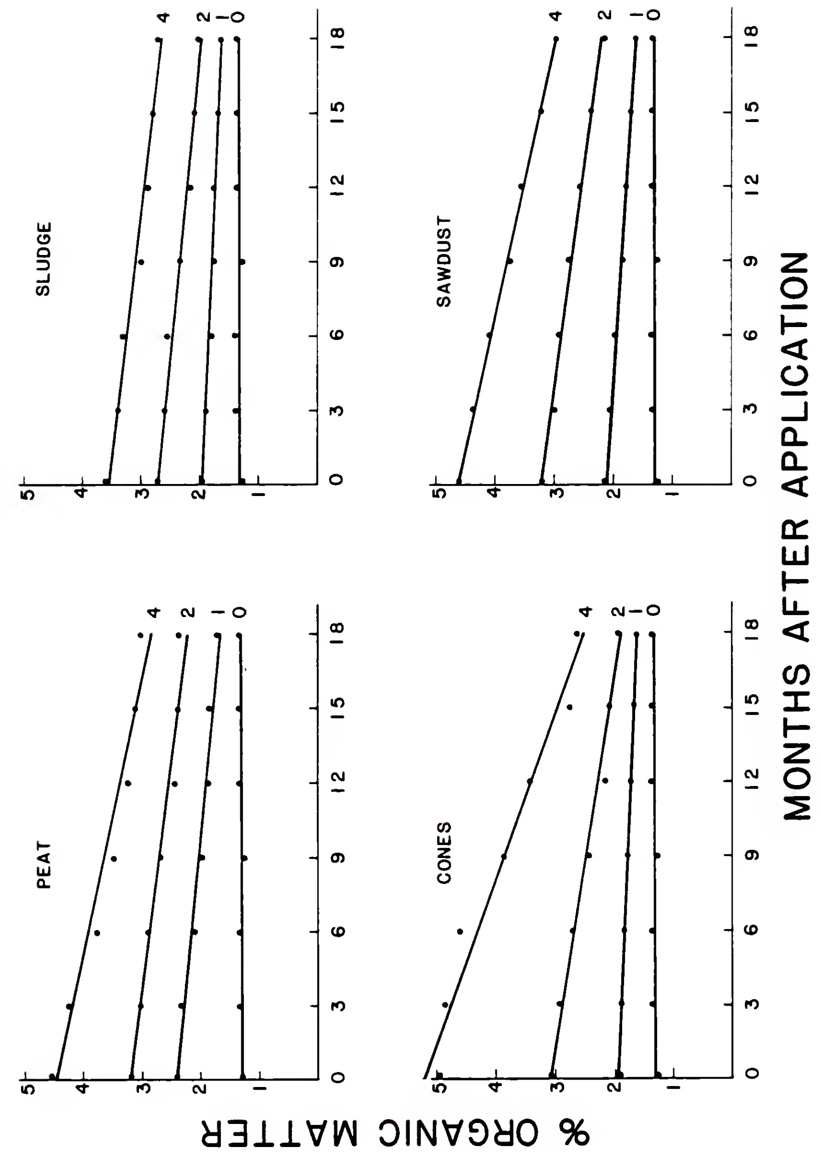
$\text{Sludge } 2 = 2.70 - .042\,T,\ r^2 = .95$; $\text{Sludge } 4 = 3.53 - .055\,T,\ r^2 = .95$;

$\text{Cones } 1 = 1.91 - .017\,T,\ r^2 = .97$; $\text{Cones } 2 = 3.06 - .066\,T,\ r^2 = .95$;

$\text{Cones } 4 = 5.19 - .147\,T,\ r^2 = .96$; $\text{Sawdust } 1 = 2.16 - .035\,T,\ r^2 = .96$;

$\text{Sawdust } 2 = 3.17 - .055\,T,\ r^2 = .96$; $\text{Sawdust } 4 = 4.59 - .091\,T,\ r^2 = .99$.

The 1980 crop was harvested in the seventh month; the soil-OM mixtures were then stored for approximately 7 weeks prior to replacement in the nursery bed.


PEAT
SLUDGE
CONES
SAWDUST
% ORGANIC MATTER
MONTHS AFTER APPLICATION
0
3
6
9
12
15
18
1
2
3
4
5

to decomposition than any of the other three materials. A more probable explanation, however, is that decomposition was reduced by the large size and low porosity of the sludge particles. Initial air drying of sludge produced firm aggregates, 78% of which were larger than 2 mm (Table 2-1). Hence, the area of soil-sludge contact was limited and exchange of O_2 and CO_2 with soil air restricted. The large fraction of coarse particles (44% > 6 mm) also produced a clumped distribution of sludge in the soil-sludge mixture. This is probably the major reason why initial OM levels were considerably lower than calculated. Apparently, this affected only the accuracy of the OM levels in the samples taken since the precision of the samples taken over the 18-month period appears good.

Laboratory incubation and field studies have shown that decomposition of other sludges is generally more rapid than observed here (Terry et al., 1979; Varanka et al., 1976; Miller 1974). Thus, sludge decomposition rates observed in the present study may be underestimates. Linear extrapolation of the equations (Fig. 2-2) shows that the OM levels in the 1, 2, and 4% rates would reach that of the control (1.3%) in 35, 33, and 40 months, respectively. Thus, decomposition appears to be somewhat proportional to application rate.

Decomposition of the shredded cones proceeded rapidly: 51, 68, and 68% for the 1, 2, and 4% rates, respectively, after 18 months. The 68% loss is the largest of any material applied at 2 or 4%. No explanation can be offered for the lower loss rate at the 1% addition, a reversal contrary to results with the other three materials. Despite the coarse size

(Table 2-1) and outward woodiness of the cone fragments, their internal structure seems susceptible to microbial attack. Extrapolation of the regressions (Fig. 2-2) shows return of OM levels to that of the control in 36, 27, and 27, months, respectively.

Losses after 18 months from the 1, 2, and 4% sawdust treatments amounted to 73, 53, and 50%, respectively. The 73% loss was the greatest of those for all materials and rates. Loss from the 2% treatment may be compared with results from a laboratory incubation study (Allison and Murphy 1963) in which 2% fresh slash pine sawdust mixed with soil lost 28% of its carbon in 12 months. This would extrapolate to 42% in 18 months, less than 53% observed in the present study.

Extrapolation of the regressions in Figure 2-2 indicates that OM levels in the 1, 2, and 4% treatments would return to that of the control (1.3%) in 25, 34, and 36 months, respectively.

If the sludge is excluded from comparison because of the particle characteristics discussed earlier, as well as its very different chemical properties (Table 2-1), then the other three materials rank as follows in respect to decomposition after 18 months (actual percentages in parentheses):

Application rate	Ranking	Calculated time for 100% decomposition
1%	sawdust (73) > peat (62) > cones (51)	25-36 months
2%	cones (68) > sawdust (53) ≈ peat (51)	27-35 months
4%	cones (68) > sawdust (50) ≃ peat (51)	27-35 months

Only the 1% cone treatment deviates from an overall decomposition ranking of 1% > 2% = 4%, within materials, and cones > sawdust ⩾ peat, within rates.

As already mentioned, reasons for the lower decomposition of the 1% cone treatment are lacking. A speculative explanation, however, is that the generally coarse particle size limited the area of soil-particle contact and hence opportunity for initial colonization by higher fungi, which expedite decomposition of lignaceous materials, especially when nitrogen availability is low. Sawdust and the higher rates of cones might have provided more numerous opportunities for such colonization.

The somewhat more rapid decomposition of cones, generally, may be attributed to the previous decomposition history of peat and (old) sawdust. The similarity of the latter two is surprising, however, in view of their very different histories and the great differences between them in nitrogen contents (3.31 vs. 0.198%, ash-free; Table 2-1). As indicated later (Table 2-3), the nitrogen contents of total OM increased (C/N decreased) as the soil-cone and soil-sawdust mixture decomposed, but never approached that of the soil-peat treatments.

Although decomposition at 18 months varied somewhat with material and rate of application, the linear extrapolations for Figure 2-2 suggest that all treatment effects upon soil OM content would disappear by 36 months. Only the 4% sludge treatment would exceed this time and, as noted, the potential decomposition rate of this material may have been underestimated. In general, the results of this study would suggest that where maximizing residence time of applied organic materials is an objective, this may best be achieved by frequent applications at the lowest rate rather than applications of the same total quantity in larger but less frequent additions. Such conclusions, however, must be modified, as indicated below.

The question of how well the microplot method predicts relative decomposition of various materials under actual field conditions cannot be answered. Direct comparison is possible only for peat, used in both the field macroplot study (Ch. 1) and the microplots. As noted, decomposition in the macroplots was about 20% after 18 months for the 2 and 3% additions as compared with about 50% for the 2 and 4% rates of the present study. Several factors may have contributed to accelerated decomposition in the latter. First among these was the intimate mixing of soil and peat, which could not be duplicated even by repeated field tillage. Additionally, harvest of the first crop and screening to remove roots fragmented the remaining peat particles and thoroughly remixed the soil. It is possible that the bucket framework (40% of the surface area), or air gaps and interfaces between the microplot mixtures and surrounding soil retarded moisture movement and so led to longer retention after rain or irrigation. Finally, soil samples were taken from 0-30 cm-depth for the microplots versus 0-15 cm for the macroplots. The 15-30-cm layer obviously is less subject to severe and rapid drying and may have been more favorable for the higher fungi mentioned earlier.

If decomposition of the other organic materials was similarly accelerated, then the calculated 25- to 36-month residence time indicated above should be extended 2 to 2½ times, to 5 - 7½ years, to represent field performance. Such duration would allow maintenance of OM levels 2 or 3 times greater than that of the control (1.3%), for example, by heavy additions (45-90 mt/ha) at intervals of 4 to 6 years.

Effects on Soil Properties

Soil reaction. Soil reactions between pH 5 and 6 are generally regarded as optimum for pine seedling production (Armson and Sadrieka 1979). The seasonal course of nursery soil pH is affected by nutrient uptake and leaching, by the effects of applied fertilizers and by the cumulative additions of bases in irrigation water. In consequence, statistical comparisons were limited to those between materials and rates within each sampling date.

Reaction of the unamended control soil increased irregularly from about pH 5.7 to 6.0 at 18 months (Fig, 2-3), presumably reflecting the excess of calcium in the irrigation water over that lost by leaching of unutilized fertilizer nitrogen (as NO_3^-) and also Cl . A total of 141 kg/ha each of N and K_2O, as KCl, was applied at intervals to the two successive pine crops grown in the microplots as described earlier in Chapter 1.

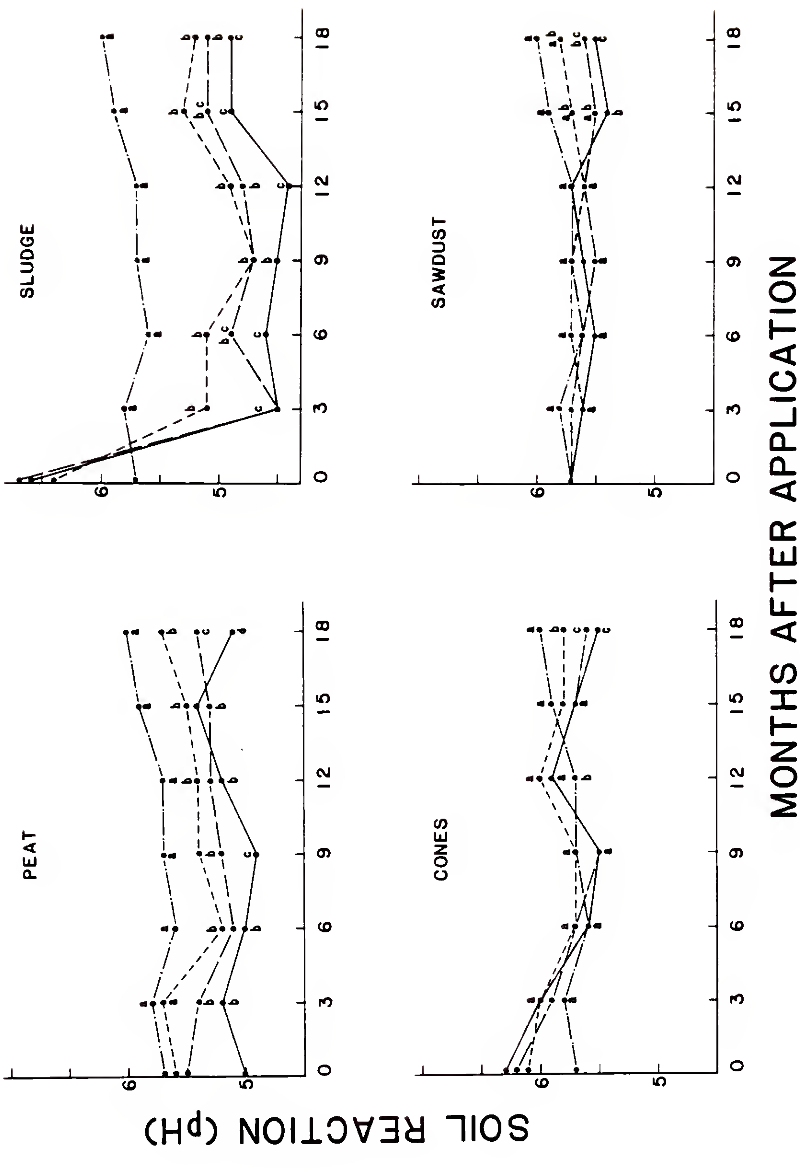
Addition of acid peat lowered the pH 0.3 unit for each 1% increase in OM (Fig. 2-3). This effect persisted throughout both seasons with reaction more or less paralleling changes in the unamended control, but at levels reflecting higher CEC.

As expected, the high base content and reaction of the sludge initially increased pH of the soil-sludge mixture. This response was abruptly reversed, with the two higher treatments falling from pH 6.6-6.7 to 4.5 at 3 months. Decreases during the first 9 to 12 months can be ascribed to nitrification and rapid leaching of NO_3^- from a material with a narrow C/N ratio (Table 2-1). The subsequent slow increase is generally similar, although steeper, to that of comparable peat treatments.

Figure 2-3. Soil reaction (pH) as influenced by four organic amendments applied at three rates. The 1980 crop was harvested in the seventh month; the soil-OM mixtures were stored for approximately 7 weeks prior to replacement in the nursery bed.

Control = — · — · —, Rate 1 = — — —, Rate 2 = —— —— ——, Rate 3 = ———— .

Values at each sample period within materials with the same letter are not significantly different (Duncan's, a = .05). Statistical analyses were not conducted on the "0" month sample.


PEAT
SLUDGE
CONES
SAWDUST
SOIL REACTION (pH)
MONTHS AFTER APPLICATION
0 3 6 9 12 15 18
5
6

The marked increase in initial pH following addition of shredded cones apparently is due to the relatively high potassium content (.34%, Table 2-1), combined with low CEC of the raw woody material. The subsequent fall of reaction to that of the unamended control at 6 months probably reflects increased CEC, hence lower base saturation, as decomposition progressed (Fig. 2-3), although some leaching may have occurred. A lesser pulse of increase at 12 months, i.e., early in the second growth period, is unaccounted for, but again followed by a decrease.

Addition of "old" sawdust decreased pH slightly below that of the controls during the first year, and somewhat more so between 12 and 18 months.

Soil nutrient status. Changes in the soil nutrient status over the 18-month study period are the net results, not only of the composition of materials (Table 2-1) and decomposition *per se* (Fig. 2-2), but also of (a) crop uptake, (b) fertilizer additions, as discussed earlier in Chapter 1, (c) production of excess NO_3^- and hence leaching of bases, (d) cumulative addition of Ca in irrigation water, and (e) leaching from soil by excess irrigation and rainfall.

Selected chemical properties of soil samples taken at 3 and 18 months after the organic additions are listed in Table 2-3. The unamended control soil showed no detectable decrease in OM, but an apparent decrease in N and K. The latter two are due to leaching and crop uptake. Despite such uptake, extractable P, Ca and Mg increased as a result of fertilizer additions (it was discovered that coarsely ground limestone

Table 2-3. Soil nutrient and OM status as influenced by four organic amendments at 3 and 18 months after application.[1]

Treatment	Rate	OM		N		(N/OM)x100[2]		P		K		Ca		Mg	
		3 mo.	18 mo.	3	18	3	18	3	18	3	18	3	18	3	18
Control	0	1.32	1.32	283	254	2.14	1.92	41	54	19	13	196	277	4.2	12
Peat	1	2.37	1.77	526	406	2.22	2.29	37	46	18	16	198	276	5.0	12
	2	3.02	2.32	791	630	2.62	2.72	36	41	18	12	200	254	5.8	12
	4	4.27	3.07	1110	839	2.60	2.73	35	38	18	12	226	292	6.1	14
Sludge	1	1.91	1.63	629	461	3.29	2.83	101	67	24	10	390	214	6.4	10
	2	2.59	2.03	1112	703	4.29	3.46	122	95	30	12	360	308	7.2	14
	4	3.40	2.63	1724	1122	5.07	4.27	223	117	50	16	572	360	9.8	20
Cones	1	1.87	1.60	318	304	1.70	1.90	47	48	38	18	290	294	5.6	14
	2	2.92	1.99	326	314	1.12	1.58	43	43	64	32	194	276	6.2	16
	4	4.82	2.63	426	403	0.88	1.53	42	42	126	62	258	256	9.0	22
Sawdust	1	2.09	1.58	296	284	1.42	1.74	47	46	20	20	250	288	5.0	12
	2	2.95	2.09	282	291	0.98	1.37	38	42	16	20	216	236	5.0	12
	4	4.32	2.94	262	306	0.61	1.06	39	38	24	24	192	234	8.0	10

1/ OM determined as loss-on-ignition; N as total; others are extractable by .05 N HC1 + .025 N H_2SO_4.

2/ C/N values of 10, 20, 30, 40, 50 are equivalent to 5.8, 2.9, 1.94, 1.45, 1.16% $\frac{N}{OM}$, respectively.

was used as a partial filler in the granular fertilizer used in 1980). Additional Ca inputs were received from irrigation water.

The high N content (2.85%) of the peat additions resulted in significant increases in total soil N. Although both OM and N levels decreased over 15 months, the N/OM ratios changed only slightly. Hence, release of available N was more or less proportional to total OM decomposition. Extractable P, Mg, and Ca increased, whereas K decreased similarly to the control, and presumably for the same reasons. Apparently, the greater CEC of the peat did not lead to greater retention of applied K. Potassium uptake by seedlings must be considered, however, as discussed later.

As with peat, the high content of N in sludge (5.7%) resulted in significant increases of total soil N. Organic matter, N, and N/OM ratios decreased over the 15-month period, with the magnitude of reduction increasing with the application rate. The reduction in N/OM ratios indicates that N was mineralized and removed from the system at a rate greater than OM was being oxidized. This effect was more pronounced at the higher application rates. Nitrogen losses between 3 and 18 months are roughly equivalent to 680, 1656 and 2437 kg/ha for the 1, 2, and 4% application rates (based on 30 cm depth and bulk density of 1.33). Those quantities are far in excess of possible seedling uptake. Such losses occur largely through leaching of NO_3^-, which in turn removes equivalent amounts of cations (Raney 1960). Although the sludge initially contained 1.55% Ca and 0.47% Mg (Table 2-1), no influence of the latter is evident from analyses at 3 months. Likewise, K contents of the sludge-amended plots are well below those of the cone treatments, although K concentrations

in the original materials are comparable. Calcium losses must have been greatest in the first 3 months when pH decreased abruptly (Fig. 2-3), but continued through to 18 months, despite Ca inputs from fertilizer materials and irrigation water.

The sludge initially contained 2.39% P, presumably in both organic and inorganic forms. Extractable quantities present at 3 months are equivalent to much less than half the additions in sludge, and decreased by 1/3 to 1/2 in the following 15 months. This decrease is not accounted for by excess seedling uptake (Table 2-6) and its mechanism is unexplained.

The addition of shredded cones, a low-N material, greatly reduced the N/OM ratio of the soil-OM mixture. Only slight losses of N occurred over the 15-month period, although OM decreased markedly. Thus, N/OM ratios increased accordingly. At 3 months those ratios were markedly lower than that of the control, but at 18 months the ratio for the 1% treatment approached that of the control (Table 2-3). Extractable Ca and P changed little over the period, while Mg increased as a result of fertilizer additions. The high content of K in the cones is reflected in high soil K at 3 months (Table 2-3). At 18 months, K levels in the cone-soil mixture decreased by roughly 50%, although still higher than the other materials. The excess K loss was not accounted for by increased crop uptake, and hence must be attributed to leaching. Additional amounts of K may also have been lost in the 0-3 month period.

As expected, sawdust had the widest C/N ratio of the four materials (Table 2-1). Over the 15-month period, OM levels decreased while N levels remained nearly constant. A marked rise in N/OM ratios reflected this disproportionate loss of OM with respect to N. Extractable P and K changed little over the period, while Mg increased as a result of fertilizer additions. Calcium levels increased as a result of both fertilizer and irrigation water additions.

At 3 months, extractable Mn had increased significantly in all treatments, except at the 1% rate of peat and the 1 and 2% rates of sawdust (Table 2-4). Increases were greatest in the cone and sludge treatments, a result of the higher Mn contents of these materials (Table 2-1). Between 3 and 18 months, the unamended soil and the cone and sawdust treatments showed no net change in Mn, while the sludge plots decreased to the level of the control,and the peat treatment increased. Excluding the sludge, Mn levels in excess of the control were presumably due to slightly greater retention of fertilizer Mn in the amended plots.

Initially, levels of extractable Zn were increased only in the sludge treatments, a result of the high Zn content of that material (Table 2-4). After 15 months, Zn levels in the sludge treatments had decreased 30-50%, but were still higher than for the other materials. The slight increases for some materials and rates over that of the control are a result of fertilizer-Zn retention.

Extractable copper concentrations were unaffected by treatment and are not presented.

Table 2-4. Double-acid extractable concentrations of Mn and Zn in soil-amendment mixtures 3 and 18 months after application.

Material	Rate	Mn		Zn	
		3 mo.	18 mo.	3 mo.	18 mo.
		ppm			
Control	0	4.2 a[1/]	4.6 a	1.0 a	3.1 ab
Peat	1	5.0 ab	6.0 abc	0.6 a	2.4 ab
	2	5.8 bc	7.2 cd	1.1 a	1.2 a
	4	6.6 cd	8.0 d	0.8 a	2.7 ab
Sludge	1	6.4 cd	5.2 ab	18.8 c	7.0 bcd
	2	7.2 d	5.6 abc	15.6 b	10.8 d
	4	9.8 e	5.8 abc	36.2 d	18.8 e
Cones	1	5.6 bc	5.2 ab	0.9 a	3.1 ab
	2	6.2 cd	6.6 bcd	0.7 a	8.2 cd
	4	9.0 e	10.2 e	1.1 a	2.8 ab
Sawdust	1	5.0 ab	5.0 ab	0.6 a	2.3 ab
	2	5.0 ab	5.8 abc	1.2 a	3.8 abc
	4	6.0 bc	5.6 abc	0.7 a	3.6 abc

[1/] Values in columns with the same letter are not significantly different (Duncan's, a = .05).

Materials with a narrow C/N ratio, such as peat and sludge, may be beneficial through supplying available nitrogen for plant growth, but leaching of excess NO_3^- after high rates of application can accelerate loss of cations. This effect is increased by materials which lower pH, since the cation exchange capacity (CEC) of OM is "pH-dependent." The reduction in CEC is in the vicinity of .2 to .3 meq/100 g per 1% OM, per pH unit, for the materials studied by Kalisz and Stone (1980). In contrast, materials with a wide C/N ratio, e.g., sawdust and cones, produce little or no NO_3^-, and hence cation losses are small. Decisions about the application rates of amendments should consider the nutritional ramifications, including pH effects.

Effects on Seedling Development

Physical parameters. Comparisons were made among the control and three rates for each organic material within each year. Since individual seedlings were the units of measure, variability was extremely high. Only a few effects proved significant, and so mean values were averaged across rates within materials (Table 2-5).

In 1980, 10 to 15 seedlings were transplanted into the microplots. The result, after transplanting mortality, was seedling densities well below the normal of 28 seedlings/0.1 m^2. Additional mortality occurred in the sludge-treated plots. The cause is unknown but presumably was either pathogenic or chemical. Excess NO_3^- and Mn or Zn solubility as the pH dropped are possible agents. In 1981, direct, operational seeding produced seedling densities nearer the normal.

Table 2-5. Physical parameters of slash pine seedlings as influenced by four organic amendments averaged across application rates in 1980 and 1981.

Material	Seedlings microplot	Height	Stem diameter	Dry weight shoot	Dry weight root	Dry weight total	Shoot/root ratio
		cm	*mm*	--- *gm/seedling*	---	---	
1980 Crop							
Control	10	17.1	3.2	1.5	0.9	2.4	1.6
Peat	11	17.8	3.7	2.0[1/]	1.3	3.3	1.6
Sludge	5	14.5	3.1	1.2	--	--	--
Cones	11	18.1	3.4	1.5	0.9	2.5	1.7
Sawdust	10	17.0	3.4	1.5	1.0	2.4	1.6
1981 Crop							
Control	28	22.5	2.7	0.9	0.4	1.3	2.4
Peat	18	21.9	2.9	1.2	0.6	1.8	2.0
Sludge	18	17.9	2.6	0.7	0.5	1.3	1.5
Cones	21	19.6	2.5	0.8	0.5	1.2	1.6
Sawdust	23	19.9	2.7	0.9	0.5	1.4	1.7

1/ Underlined values are significantly different from the control (Duncan's, a = .05).

Mean weight of seedlings from the peat treatments was greater than that of the controls, although only shoot weight in 1980 and root weight in 1981 attained significance. Seedlings from the peat treatments were also heavier than those from any other material. Reasons for this superiority are obscure but may include greater nitrogen availability, improved soil physical properties, or even growth stimulating substances from the peat (Lee and Bartlett 1976).

Seedlings from the sludge treatments were generally smaller and lighter than those of the controls or any other amendment. Seedling height decreased as application rate increased. The lower weight obviously is not due to lack of available N or P (Table 2-3, 2-6), but may be associated with the tissue concentrations of Mn and Zn nearly threefold greater than from any other treatment (Table 2-7). As mentioned under Methods, a reliable estimate of root weight was not obtained in 1980 because of low seedling density in the microplots.

Overall, seedlings from the cone and sawdust treatments differed little from those of the controls except in having slightly--but non-significantly--larger root systems in the second year. This lack of difference is surprising in view of the wide C/N ratios of the amendments, and especially so in the second year when only 34 kg/ha of fertilizer-N was applied.

Chemical parameters. The effects of treatment on elemental concentrations and contents were compared as described for the physical parameters. Since few effects were significant, values were averaged across rates, and thus one value per variable is presented

Table 2-6. Element concentrations (% dry weight) and contents (mg/seedling)[1/] of slash pine seedling shoots as influenced by four organic amendments averaged across application rates.

Material	Seedlings microplot	N		P		K		Ca		Mg	
		%	mg/sdln	%	mg /sdln	%	mg/sdln	%	mg/sdln	%	mg/sdln
1980 Crop											
Control	10	1.5	21.4	.16	2.3	.71	10.4	.50	7.3	.09	1.3
Peat	11	1.3	26.5[2/]	.17	3.4	.67	13.5	.38	7.6	.09	1.8
Sludge	5	2.2	25.2	.20	2.2	.71	3.3	.67	7.8	.14	1.7
Cones	11	1.3	20.6	.17	2.7	.80	12.5	.37	5.8	.09	1.3
Sawdust	10	1.4	20.5	.16	2.4	.74	10.9	.45	6.8	.09	1.3
1981 Crop											
Control	28	1.2	11.2	.17	1.6	.71	6.6	.52	4.9	.11	1.0
Peat	13	1.3	16.0	.19	2.3	.73	8.5	.48	5.6	.10	1.2
Sludge	18	1.4	10.1	.23	1.6	.65	4.8	.53	4.0	.13	0.9
Cones	21	1.3	9.9	.20	1.5	.83	6.3	.42	3.2	.10	0.8
Sawdust	23	1.3	11.9	.19	1.8	.80	7.2	.43	3.8	.10	0.9

[1/] Seedling contents may differ from those calculated from concentration x weight (Table 2-5) because of rounding errors.

[2/] Underlined values are significantly different from the control (Duncan's, a = .05).

Table 2-7. Microelement concentrations (ppm dry weight) of 1981 slash pine seedling shoots as influenced by four organic amendments averaged across application rates.

Material	Seedlings per microplot	Cu	Mn	Zn
		ppm		
Control	28	5.4	95	61
Peat	18	5.2	184[1/]	61
Sludge	18	6.1	486	180
Cones	21	5.6	161	63
Sawdust	23	5.7	193	60

[1/] Underlined values are significantly different from the control (Duncan's, a = .05).

for each material per year (Table 2-6). Significant differences among rates within a material are mentioned in the discussion that follows. Seedling densities vary between years as described earlier.

The peat treatment had no significant effect on N and P concentrations in either year. Greater shoot weights, however, resulted in greater absolute contents of both elements (Table 2-6). Nitrogen and P concentrations did not vary with peat rate, which indicates little or no benefit from the high levels of N that presumably were available in the higher peat treatments (Table 2-3). Although the control seedlings dropped from 1.5% N in 1980 to 1.2% N in 1981, the seedlings from the peat treatment did not change from 1.3%. The reduction in N concentration is attributed to the low amount of fertilizer-N applied (34 kg/ha). Since the seedlings from the peat-amended plots did not show the drop in N concentration, peat must have been a stabilizing influence on the N-nutrition of the seedlings. Calcium concentrations were significantly lower in 1980 than in the control seedlings, which may have resulted from reduced availability of this element as increased CEC from the peat additions lowered its percentage saturation on the exchange complex.

The sludge treatments resulted in greater tissue concentrations of N, P, Ca and Mg in 1980 (Table 2-6), reflecting the high content of these elements in the sludge. These increases, however, were proportionally less than the large differences between the soil concentrations of the sludge treatments and the control (Table 2-3). As previously described, large amounts of N were lost from the sludge-amended soils,

reducing the initially high cation content. Consequently, only P concentration was significantly greater in the 1981 crop. This emphasizes the potential for cation leaching when large quantities of high-N organic materials are applied.

Nitrogen concentrations of shoots from the cone treatments did not differ from the controls in either year, despite the wide C/N ratio of the amended soil. Shoot content of N was lower in 1981 due to lower weight. Potassium concentrations were higher in both years, although significantly so only in 1980. This reflects the relatively high K content of the cones. Although soil K diminished between 3 and 18 months (Table 2-3), its level was still higher than in the other treatments,

As compared with the controls, the sawdust treatments had little influence on elemental concentrations or contents in either year (Table 2-6). The only exception to this was Ca concentrations in 1981, which, as in the cone treatments, were lower than in control seedlings. The 20-year exposure of sawdust to weathering and decomposition processes doubtless had removed the easily and moderately decomposable fractions although the C/N ratio was still > 300. The relative inertness to rapid decomposition, coupled with low contents of N, P, K, Ca, and Mg, resulted in the sawdust having less chemical influence on the soil and subsequent plant growth than the other materials tested.

None of the amendments significantly increased shoot Cu concentration (Table 2-7), despite the wide differences in concentration between the sludge (450 ppm) and other materials (3 ppm). Shoot Mn concentrations were roughly 2 times greater for the peat, cone, and sawdust

treatments, and 5 times greater for the sludge, as compared to the unamended control (Table 2-7). This difference was roughly proportional to the Mn composition of sludge and cones, while not so for peat and sawdust (Table 2-1). Tissue concentrations of zinc were only 3 times greater in the seedlings from the sludge treatment than from the controls, while the other treatments had no apparent effect. This is despite the fact that sludge contained nearly 100 times more Zn than the cones, which had 3 to 7 times more than peat or sawdust (Table 2-1). Additional Zn was added to the system from fertilizer materials and from the galvanized hardware cloth used to screen out roots when the seedlings were harvested in 1980. The latter contributed zinc to the soil (Table 2-4) and subsequently to the seedlings in 1981. Seedlings from the peat-treated microplots had Zn concentrations 20 to 30% greater than seedlings from the field macroplot study (Ch. 1, Table 1-7). Additionally, soil samples taken at the end of each study from plots which had received the lowest rate of peat showed 4 times more Zn in the microplots (2.4 ppm; Table 2-4) than in the field macroplots (0.67 ppm; Table 1-4).

Effects of Mycorrhizae and Incidence of Charcoal Root Rot

No visible evidence of charcoal root rot infection was found in any treatment.

The influence of treatment on percentage of short roots colonized by ectomycorrhizal fungi is presented in Table 2-8. Peat treatments markedly increased colonization in both years, as compared to the unamended control. In 1980, the lower rates of sludge treatments had no influence, whereas the higher rate increased colonization, despite the

Table 2-8. Approximate percentage of short roots colonized by ectomycorrhizal fungi as influenced by treatments.

Material	Rate	% Short roots colonized 1980	1981
Control	0	37	18
Peat	1	58	44
	2	70	46
	4	43	57
Sludge	1	35	38
	2	35	19
	4	62[1/]	26
Cones	1	39	43
	2	37	37
	4	27	47
Sawdust	1	31	36
	2	27	21
	4	21	26

[1/] Only 12 seedlings were alive at harvest.

poor seedling survival. Contrastingly, in 1981 colonization in the low rate treatment was twice as great as for the controls, while the two higher rates showed only slight increases. Colonization at the highest rate of cone addition was lower than the controls in 1980, but in 1981 all rates were superior to the controls. Similarly, all rates of sawdust addition resulted in a smaller percentage of mycorrhizal short roots in 1980, but an increase in 1981. The reduction in colonization by the wide C/N ratio materials (cones and sawdust) may be due to early effects on seedling nutrition.

Utility of the Microplot Method

The microplot method developed in this study proved to be a satisfactory means of comparing decomposition of various materials at several rates. The significance of such information awaits further comparisons of decomposition in microplots vs. field plots for cones, sludge and sawdust, as was done for peat. A comparison of selected features from the control and peat 2 treatments follows:

	Decomposition		Correlation		1981 seedling development			
					dry weight		shoot N	
	Micro	Macro[1]	Micro	Macro	Micro	Macro	Micro	Macro
	%		r^2		g/m^2		%	
Control	0	0	---	---	364	729	1.2	1.1
Peat 2	51	21	.95	.21	504	941	1.3	1.3

[1] Field macroplot data are from unfumigated plots (Ch. 1).

This comparison indicates that decomposition was more rapid and measured with greater precision in the microplots than in the large-scale field plots. Reasons for this were discussed earlier. Extrapolating the residence time of peat in the microplots to performance under actual field conditions requires multiplying by a factor of 2 - 2½ times.

Dry weight of seedlings from the microplots was roughly half that of seedlings from the macroplots. The weight ratio of the control and peat 2 treatment seedlings is roughly proportional in both studies (i.e., microplot, .72; macroplot, .77). Shoot N concentrations in both studies seem to correlate almost directly. Thus, it appears that the microplot method predicts relative differences in seedlings grown in amended and unamended soil.

Modifications of the methodology that may improve precision are (a) additional replications, and (b) maintenance of uniform seedling number in each microplot. The latter may be achieved by sowing a 10 to 20% excess of seeds, then thinning to the desired density several weeks after germination. Also, pre-plant fertilizer mixtures could be incorporated into the soil-OM mixtures to more closely parallel field conditions.

The method was inexpensive in terms of materials and was labor intensive for only a few 2 to 3-day periods when the plots were installed and lifted at the beginning and end of the growing season. Because the microplot containers were made of sturdy plastic they can be used in subsequent years.

With some modifications as described, the microplot method appears to be a useful means of testing a variety of organic materials, combinations, and application rates with respect to OM decomposition, effects on soil chemical properties, and seedling responses.

General Conclusion

Half or more of the added OM decomposed in the 18-month period of study, regardless of material or rate. The exception was a 44% loss from the 4% sewage sludge application, and here decomposition probably was retarded by coarse particle size and drastic changes in the soil chemical environment. Losses from shredded cones, the only material not subjected to prior decomposition, were greater than from the other three materials, which in turn were roughly comparable. Within each material and rate, decomposition was a linear function of time. In contrast, OM content of the control soil (1.3%) did not change perceptibly.

Peat-amended soils maintained a lower reaction throughout the study period. Cones and sawdust had little influence except in the last 3 to 6 months. Reaction in the sludge-treated plots at first increased to above pH 6, then lowered below pH 5 as nitrification occurred.

The most notable effects on soil concerned nitrogen transformations. Peat decomposed without appreciable changes in N/OM ratios, and thus served as a source of "slow release" N for seedling uptake over the growing season. The high content of readily mineralized N in sludge resulted in leaching of excess NO_3^- and concurrent losses of cations, especially calcium.

In terms of seedling growth, the most notable effects were first year mortality and high tissue concentrations of Mn and Zn in the sludge treatments. Surprisingly, cones and sawdust did not reduce growth or nitrogen uptake below that of the control despite high C/N ratios in the soil.

The microplot method used to test the materials proved satisfactory but could be improved with some modifications. Overall, the response of seedlings, soil chemical properties, and OM residence time varied with organic material and rate of application. Ideally, the nature of these responses should be determined prior to the full-scale operational use of any exogenous organic material.

CHAPTER III
LABORATORY INCUBATION OF VARIOUS ORGANIC MATERIALS

Introduction

For many years exogenous sources of organic materials have been used as supplements to cover crops in attempts to maintain the organic matter content of forest nursery soils. Many studies have evaluated the effects of organic matter additions on plant growth and, to a lesser extent, on soil properties (Brown and Myland 1979, Davey 1953, Wilde and Hull 1937). In contrast, with the exception of the notable work by Allison and Murphy (1963), Allison and Klein (1961), Pinck et al. (1950), and Allison et al. (1949), little attention has been given to characterizing the decomposition of various types and application rates of organic materials. Allison and Murphy (1963) concluded that rates of decomposition of sawdust and bark differ markedly with tree species. Since the variety of organic materials available for application to nursery soil differs greatly in physical and chemical properties, field testing of the actual effects on soil and seedlings is eventually necessary.

Full-scale field testing, even in small plots, however, requires time and effort, and is subject to variability induced by weather and management. Such effort and variability would be reduced if laboratory incubation of organic materials could serve as a screening test for rates of decomposition. Such a test might also provide more exact information on the course of decomposition than is possible to obtain under field conditions. Accordingly, a laboratory incubation study was designed

to examine the same materials used in the field microplots (Ch. 2), thus allowing a comparison of the methods. Two additional materials, pulp mill waste and fresh pine bark, were included.

Materials and Methods

Experimental Design and Conduct

The decomposition of peat, old slash pine sawdust, fresh slash pine bark, shredded cones, sewage sludge, and pulp mill waste was evaluated by measuring CO_2 evolution from mixtures of these materials with a nursery soil incubated at 22° C. The soil used was from bulk samples taken prior to peat application in the field macroplot study (Ch. 1). The pine bark and pulp mill waste were obtained from industrial mills, and other materials were the same as used in the prior studies (Ch. 1,2). The mill waste consists largely of short cellulose fibers and wood residues not used in paper manufacturing. All materials were ground to pass a 20 mesh sieve prior to mixing with soil. Table 3-1 presents the chemical characteristics of materials and nursery soil.

Erlynmeyer flasks (125 ml) were prepared with 100 g of nursery soil mixed with the equivalent of 2 g ash-free organic material (equivalent to 44.8 mt/ha) and 0.25 g NH_4NO_3. The mixtures were then wetted to field capacity. Peat and mill waste were also added at rates of 1 and 3 g of ash-free material/100 g of soil. Controls were prepared identically but without organic addition. Three replicates of each treatment, including controls and blanks (empty flasks) resulted in a total of 36 flasks. These were arranged in a completely randomized fashion.

Table 3-1. Chemical characteristics of organic materials and unamended soil.[1/]

Material	pH	Ash	C	N	C/N	P	K	Ca	Mg	Cu	Mn	Zn
		---- % ------				----------	----------	----------	ppm	----------	----------	----------
Unamended soil	5.8	99	0.7	0.02	35	44	35	149	9	[2/]	5	0.4
Peat	4.5	14	53.7	2.85	19	160	90	1250	415	3	5	2
Sludge	6.7	24	42.7	5.69	8	23900	2750	15500	4690	450	84	1249
Cones	6.2	1	56.5	0.30	188	215	3400	225	405	3	28	14
Sawdust	4.5	4	61.6	0.19	324	25	55	325	70	3	9	4
Bark	4.0	1	53.4	0.17	314	100	410	1575	215	2	12	13
Mill waste	8.1	30	39.0	0.19	205	621	--[3/]	--	--	--	--	--

[1/] P, K, Ca, Mg, Cu, Mn, Zn are expressed as extractable (.05 N HCl + .025 N H_2SO_4) for soil and total for organic amendments.

[2/] Not determined.

[3/] These elements were not determined due to lack of a suitable ashing procedure for this material.

The incubation system followed the basic procedure described by Stotzky et al. (1958). Each incubation flask was connected by plastic tubing to two 2.5 cm x 20 cm glass test tubes (Fig. 3-1). The first tube was a precaution against the possible back-flow. The second contained 20 ml 0.1 N NaOH to absorb CO_2. Air supplied to the incubation flasks was scrubbed of CO_2 and humidified by passing through flasks containing 0.3 N NaOH and water, respectively.

The possible influences of moisture and available N and C on limiting microbial respiration in the flasks were examined near the end of the study. Each flask received 1.5 ml H_2O at week 17, 0.1 g NH_4NO_3 in 2 ml H_2O at week 19, and 135 mg glucose in 1 ml H_2O at week 27.

Chemical Analysis

Carbon dioxide evolution was determined by titration of the NaOH with 0.1 N HCl at weekly intervals for 30 weeks according to procedures outlined by Stotzky et al. (1958).

The chemical composition of the organic materials was determined by methods described in the prior studies (Ch. 1, 2). The methods used for the bark and mill waste were the same as those used for previously described sawdust.

Statistical Analysis

Differences in CO_2 evolution among the treatments were evaluated using general linear model procedures (Barr et al., 1979). Comparisons were made among all materials at the common rate, among the three rates of peat, and among the three rates of mill waste. Weekly CO_2 values were

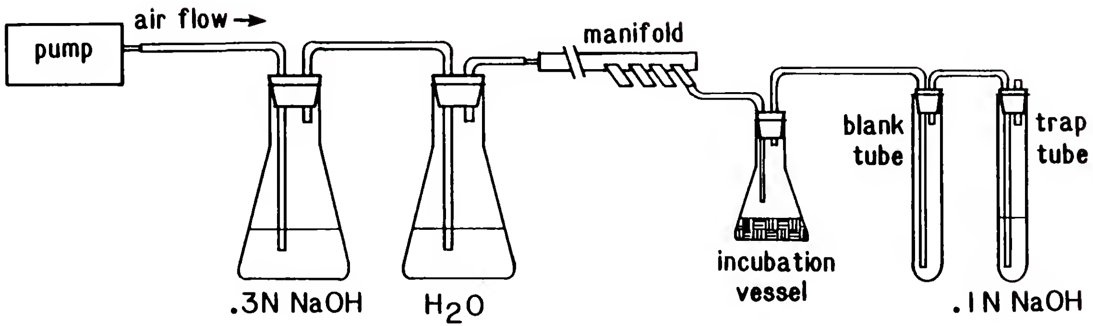


Figure 3-1. Schematic of laboratory incubation apparatus showing incubation vessel and CO_2 trap for 1 of 36 units. All flasks received air from one manifold.

summed by month. The monthly means were compared using Duncan's multiple range test (Snedecor and Cochran 1967). The analysis of variance designs used for comparisons are presented in Table 3-2.

Results and Discussion

CO_2 Evolution as Influenced by Amendment

Mean monthly CO_2 evolution varied considerably among materials (Table 3-3). All treatments showed an initial flush of microbial activity due in part to re-wetting the air-dried soil. After 1 month, sludge and mill waste had evolved six times, and the other materials two times more CO_2 than the control. Thus, the soil itself was responsible for only part of the total CO_2 output, with the remainder due to the material, presumably from the most easily decomposed fraction. The mill waste and sludge evidently had larger fractions of easily oxidized C than the other materials. Although not measured, the sludge and mill waste must have increased pH of the mixtures (Table 3-1), and unlike the nursery environment, there was no leaching of NO_3^-. Hence, the several mixtures created very different chemical environments. It is probable that the high pH mixtures favored high bacterial populations.

Differences during the second and third months were more pronounced, with CO_2 evolution rates following the order: mill waste > sludge > bark $\simeq$ cones $\simeq$ sawdust > peat > control. This pattern remained fairly stable for the remainder of the incubation time (Table 3-3), but the magnitude of the differences became smaller. This, coupled

Table 3-2. Analysis of variance designs used for comparisons of CO_2 evolution among materials and rates. One month is the sum of 4 weeks.[z]

Material comparison			Rate comparison	
Source	d.f.		Source	d.f.
Treatment	6		Rate	2
Rep (treatment)	14	--error a--	Rep (rate)	6
Month	6		Month	6
Month x treatment	36		Month x rate	12
Month x rep (treatment)	84	--error b--	Month x rep (rate)	36
Total	146		Total	62

Table 3-3. Monthly (4 week) CO_2 evolution from 100 g of nursery soil incubated with 2 g (ash free) organic material from several sources.

Month	Control	OM source					
		Peat	Sludge	Cones	Sawdust	Bark	Mill waste
1	24.9 d[1/]	41.7 cd	176.7 a	63.6 c	59.6 c	58.7 c	134.4 b
2	2.7 e	6.2 e	64.8 b	18.5 cd	13.4 d	22.8 c	156.5 a
3	2.2 e	4.7 e	31.6 b	13.2 c	9.6 d	13.1 c	141.0 a
4	1.3 d	7.6 cd	20.2 b	7.8 cd	12.0 c	7.6 cd	73.2 a
5 * **	3.7 b	8.5 b	12.6 b	10.7 b	9.7 b	3.2 b	31.7 a
6	10.4 b	15.2 ab	18.4 ab	20.4 ab	19.8 ab	9.3 b	37.3 a
7	4.3 b	8.0 ab	16.8 ab	8.6 ab	9.9 ab	8.5 ab	20.2 a
8 ***	47.7	53.4	48.0	39.0	41.0	56.1	45.9
Σ 1-7	49.5	91.9	341.1	142.8	134.0	123.2	594.3

1/ Values in rows with the same letter are not significantly different (Duncan's, a = .05).

* 1.5 ml H_2O added at week 17.

** 0.1 g NH_4NO_3 in 2 ml H_2O added at week 19.

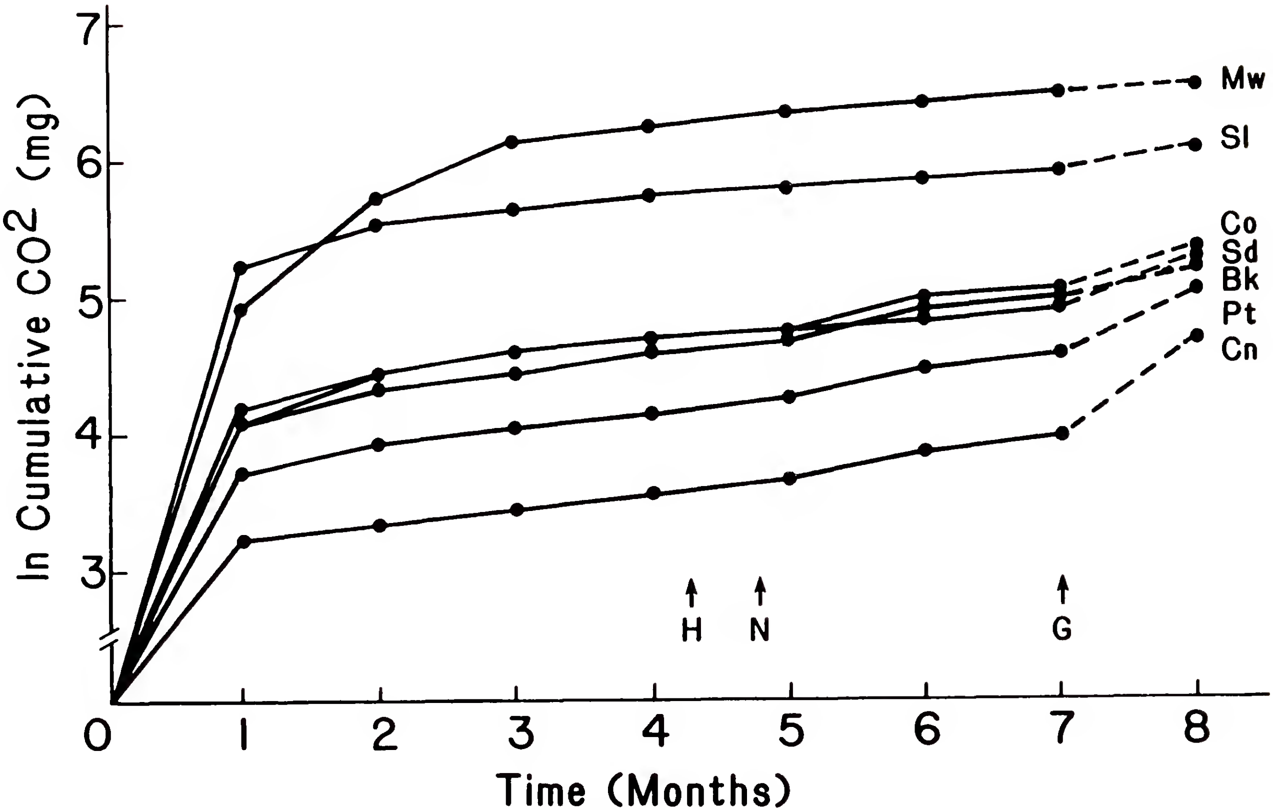
*** 135 mg glucose in 1 ml H_2O added at week 27.

with greater variability among replicates for unknown reasons, resulted in greater error and hence less precision in identifying differences in the later months of incubation.

Bark, cones, sawdust and peat reached an approximate steady state of CO_2 evolution in 1 month, the sludge in 2¼ months, and the mill waste not until 4 months. At the beginning of the fifth month the series of additions described in the Methods section were made to determine what factor was limiting microbial respiration. There was no response to the water addition at 17 weeks, indicating that moisture was not limiting respiration. Additional N at week 19 increased CO_2 evolution by 18% in mill waste, and up to 190% in bark (Table 3-3, months 5 and 6). Although the relative increases between the fifth and sixth month were large, the absolute amounts of CO_2 evolved were small with respect to the initial carbon addition. The immediate, and more or less uniform increase in CO_2 production in all treatments upon addition of glucose in week 27, demonstrates that available carbon had been a limiting factor (Table 3-3, month 8).

Examination of cumulative CO_2 evolution (Fig. 3-2) shows that after 7 months the percentage of added carbon remaining was as follows: mill waste, 89.7; sludge, 93.0; sawdust, 98.2; cones, 97.8; bark, 98.2; peat, 99.1. Although the amount of carbon oxidized appears low, given the length of the incubation period, the results parallel those of Allison and Klein (1961) for wood and bark particles of several conifer species. They found that less than 7% of the added carbon was oxidized during a 2-month period. They suggested two explanations: (a) salt concentration from nitrates, and (b) acidity resulting from nitrification.

Figure 3-2. Cumulative CO_2 evolution (expressed as natural logarithms) from 100 g of nursery soil amended with 2 g ash-free OM from several sources. Mw = mill waste, Sl = sludge, Co = cones, Sd = sawdust, Bk = bark, Pt = peat, Cn = control. H = 1.5 ml H_2O added at week 17; N = 0.1 g NH_4NO_3 in 2 ml H_2O added at week 19; G = 135 mg glucose in 1 ml H_2O added at week 27.



ln Cumulative CO2 (mg)
7
6
5
4
3
0
1
2
3
4
5
6
7
8
Time (Months)
H
N
G
Mw
Sl
Co
Sd
Bk
Pt
Cn

The same factors may have reduced CO_2 evolution in the current study given the liberal amount of N supplied as NH_4NO_3. An additional factor may have been a reduction in gas exchange due to fine organic particles accumulating on the soil surface and reducing the pore sizes at the soil-air interface. For example, the CO_2 evolved from the sludge treatment was roughly half of that measured by Agbim et al. (1977) when incubating various mixtures of spruce sawdust and sewage sludge in soil. In that study, sludge alone (22.4 mt/ha) + soil lost 28% of the added carbon in 1 year, whereas in the current study the 44.8 mt/ha rate lost 7% in 7 months.

The percentages of added carbon lost are equivalent to the percent OM lost, which for the materials are as follows: mill waste, 10.3; sludge, 7.0; sawdust, 1.8; cones, 2.2; bark, 1.8; peat, 0.9. The considerably lower decomposition rates in this study as compared with those of Figure 2-2, indicate that the incubation procedure underestimates the decomposability of the materials when subjected to field conditions. Comparison of materials, moreover, shows that sludge decomposed more rapidly than cones, sawdust, and peat, whereas in the microplot study (Ch. 2) sludge was more resistant than cones, and roughly equivalent to sawdust and peat. Considering that the materials in the incubation study were finely ground, the above results add support to the suggestion that sludge decomposition in the microplot study was reduced by coarse aggregate size of the sludge particles which limited contact with the soil.

Differences between the two studies are presumably due to the very differrent environmental conditions under which decomposition occurred. These conditions include temperature, moisture and chemical regimes, as well as more variable microbial populations in the field study, including rhizosphere populations.

Since the incubated materials were not subject to leaching, mineralized ions, NO_3^-, and H^+ accumulated. This may have resulted in concentrations unfavorable for higher fungi.

CO_2 Evolution as Influenced by Amendment Rate

Comparisons of CO_2 evolution among the three rates of peat or mill waste show only a few differences which occurred between 2 and 5 months (Table 3-4). Subsequently, unexplained experimental variability prevented large mean differences among rates from being declared significant (Table 3-4, months 6 and 7).

Examination of cumulative CO_2 evolution (Fig. 3-3) shows the percentages of added carbon lost as follows: peat 1, 0.2; peat 2, 0.9; peat 3, 1.0; mill waste 1, 11.4; mill waste 2, 10.3; mill waste 3, 7.5. Thus, as application rate increased, peat decomposition rate increased while that of mill waste decreased. Losses from the corresponding application rates in the field microplot study (Ch. 2, 4% rather than 3%) after 7 months are as follows: peat 1, 24.1; peat 2, 19.8; peat 4, 19.8. The corresponding application rates in the full-scale field study (Ch. 1) show decomposition rates after 7 months as follows: peat 1, 0; peat 2, 7.0; peat 3, 6.3. The magnitude of the losses are very different among

Table 3-4. Monthly (4 week) CO_2 evolution from 100 g of nursery soil incubated with 1, 2, and 3 g (ash free) peat or pulp mill waste.

Month	Material / Rate	Peat 1%	Peat 2%	Peat 3%	Mill waste 1%	Mill waste 2%	Mill waste 3%
		mg					
1		36.4[1/]	41.7	48.7	100	134	121
2		4.3 b	6.2a	6.5a	68 b	156 a	141 a
3		3.1 b	4.7 a	4.7 a	43 c	141 a	133 b
4		1.1 b	7.6 a	4.9 ab	40 b	73 a	87 a
5	* **	0.0 b	8.5 a	8.8 a	35	32	63
6		2.3	15.2	22.6	41	37	61
7		4.6	8.0	18.9	27	20	40
8	***	48.0	53.4	51.5	49	46	54
Σ 1-7		51.8	91.9	115.1	354	593	646

1/ Within rows and within materials, values with the same letter or no letter are not significantly different (Duncan's a = .05).

* 1.5 ml H_2O added at week 17.

** 0.1 g NH_4NO_3 in 2 ml H_2O added at week 19.

*** 135 mg glucose in 1 ml H_2O added at week 27.

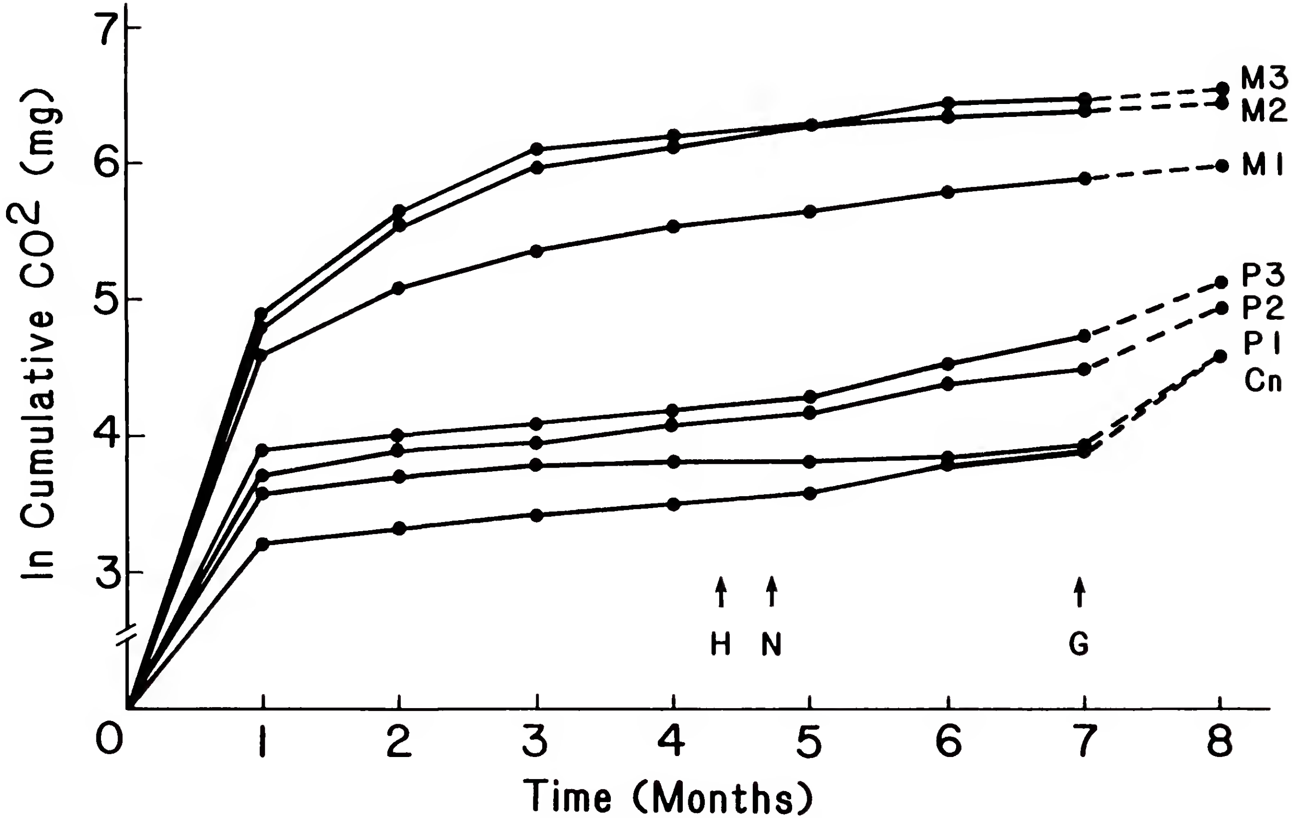


Figure 3-3. Cumulative CO_2 evolution (expressed as natural logarithms) from 100 g of nursery soil amended with three rates of pulp mill waste (M1, 2, 3) and peat (P 1, 2, 3). Subscripts refer to g of ash-free OM added. H, N, G are as listed in Figure 3-2.

the studies, and decomposition in the microplot study (Ch. 2) was greatest at the 1% application rate but conversely in the other two studies. Nevertheless, the studies agree in showing similar rates of loss from the two higher rates, respectively.

Utility of the Method for Predictive Purposes

A simple, easily maintained incubation system such as the one used in this study may be useful for initial characterization of organic materials being considered as prospective nursery soil amendments. Although an extrapolation to field conditions is limited, the results nonetheless provide comparative data on amounts of easily oxidized C and effects of application rates on decomposition.

The results of this study indicate that unaltered tree components, such as bark, sawdust and cones, have similar decomposition rates. In contrast, sludge and mill waste, although subjected to previous chemical and biological degradation, have considerably greater carbon oxidation rates. Relative to the other materials, peat oxidizes slowly--which is consistent with the results of the field microplot study (Ch. 2). The present study also shows that the residence time of added C varies with the source and rate of application as demonstrated in Chapter 2.

The laboratory incubation procedures as used in this study did not provide reliable estimates of the decomposition rates of the same organic amendments tested under field conditions. A suggested modification of the procedure would be to reduce the nitrogen applied and to intermittently mix the soil + OM mixtures to increase surface area and facilitate gas exchange.

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BIOGRAPHICAL SKETCH

Kenneth Richard Munson was born to Floyd Richard and Mary Louise Munson on September 16, 1952, in San Jose, California. His schooling through the ninth grade was in San Jose, and thereafter in Medford, Oregon. Following graduation from high school there in 1970, he entered Oregon State University and received the Bachelor of Science degree in wildlife science in 1974. Subsequently, he was employed by the U.S. Forest Service as a biological technician, and then employed by the U.S. Bureau of Land Management as a wildlife biologist. In 1977, he returned to Oregon State University and entered graduate school, and earned the Master of Science degree in soil science, emphasizing forest soils, in 1979. In the same year he continued graduate study at the University of Florida and received the Doctor of Philosophy degree in soil science in December 1982.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Dr. Earl L. Stone, Chairman
Professor of Soil Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Dr. William L. Pritchett
Professor of Soil Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Dr. Edward L. Barnard
Assistant Professor of Plant Pathology

This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the Doctor of Philosophy.

December 1982

G. L. Zachariah
Dean, College of Agriculture

Dean for Graduate Studies and Research